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J C Branner

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EDITED BY

THE ASSISTANT-SECRETARY OF THE GEOLOGICAL SOCIETY.

Quod si cui mortalium cordi et curæ sit non tantum inventis hærere, atque iis uti, sed ad ulteriora penetrare; atque non disputando adversarium, sed opere naturam vincere; denique non belle et probabiliter opinari, sed certo et ostensive scire; tales, tanquam veri scientiarum filii, nobis (si videbitur) se adjungant.
—*Novum Organum, Præfatio.*

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CORRIGENDA.

Proc. page 7, line 6 from top, *for* 'South' *read* 'North.'
Proc. page 13, line 15 from top, *for* '15 1 7' *read* '115 1 7.'
Page 85, line 11 from bottom, *for* 'in the year 1842' *read* 'about the year 1831.'
Page 89 (section), Rizama should be to the left, not to the right of the two-ridged hill.
Page 103, line 11 from top, *for* 'hone like' *read* 'bone-like.'
Page 103 (Explanation of Pl. VIII.), *for* 'Ciripuru' *read* 'Ciripiru.'
Plate VIII. In the scale of kilometres, *for* '10, 20, 30' *read* '20, 40, 60.'
Plate VIII. In the key-map of S. America, the highlands of Brazil are erroneously represented as consisting of mountain-ranges, whereas they are for the most part gently-undulating table-lands intersected by deep river-valleys.
Page 110, line 18 from top, *for* 'Sarana' *read* 'Tarana.'
Page 117, line 5 from top, *for* 'microscopic' *read* 'macroscopic.'
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Page 291, note line 1, *for* 'seciton' *read* 'section.'

THE

QUARTERLY JOURNAL

OF

THE GEOLOGICAL SOCIETY OF LONDON.

VOL. L.

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1. NOTES *on the* OCCURRENCE *of* MAMMOTH-REMAINS *in the* YUKON DISTRICT *of* CANADA *and in* ALASKA. By GEORGE M. DAWSON, C.M.G., LL.D., F.R.S., F.G.S., Assistant Director of the Geological Survey of Canada. (Read November 8th, 1893.)

THESE notes, relating primarily to the occurrence of remains of the Mammoth in the geographical valley of the Yukon River, are the result of a correspondence between Mr. H. Moody of the Canadian Pacific Railway Co., the Assistant Secretary of the Geological Society, and the writer, respecting statements which had reached Mr. Moody from a friend resident in the extreme north-western part of the Dominion of Canada. It has been suggested that a brief notice of the facts in this connexion, so far as these are known, may be of some interest to the Geological Society.

The original discovery of bones of the Mammoth in the Yukon region is due to Mr. Robert Campbell, an officer in the service of the Hudson's Bay Company, who between 1840 and 1852 travelled through and established trading-posts in the upper valley of the Yukon, and was the first white man to penetrate this remote part of North America.

In a brief account of his explorations, printed at Winnipeg in 1885, Campbell writes:—"I saw the bones, heads, and horns of Buffaloes [Musk-Oxen ?]; but this animal had become extinct before our visit, as had also some species of Elephant, whose remains were found in various swamps. I forwarded an Elephant's thigh-bone to the British Museum, where it may still be seen".[1]

[1] 'The Discovery and Exploration of the Yukon (Pelly) River,' Winnipeg, 1885.

As Campbell's posts on the Upper Yukon were finally abandoned in 1852, the bone thus referred to by him must have been sent out before this date. It was a tibia, not a thigh-bone, and was described by Sir John Richardson in 1855 as referable to *Elephas primigenius*. Richardson states that it was identical in form with, though larger than, a corresponding bone of the same animal brought back by Capt. Beechey from Eschscholtz Bay. The skeleton of which it formed part was said to be complete when found; but most of the bones were lost by the Indians who extracted them for Campbell. According to a statement subsequently obtained from Campbell, these bones were found at some place not far from the former site of Fort Selkirk, at the confluence of the Lewes and Pelly Rivers.[1]

Dr. W. H. Dall in 1866-67, during his connexion with the Western Union Telegraph Expedition (abandoned on the completion of the Atlantic Cable), visited a number of places in the lower valley of the Yukon, within what is now the Territory of Alaska. In the volume which resulted from his explorations, and in other publications, he frequently mentions the occurrence of Mammoth-remains in this region, writing in one place as follows:—

"Wild and exaggerated stories have found a place, even in official documents, in regard to fossil ivory. This is not uncommon in many parts of the valley of the Yukon and Kuskoqúim. It is usually found on the surface, not buried as in Siberia, and all that I have seen has been so much injured by the weather that it was of little commercial value. It is usually blackened, split, and so fragile as to break readily to pieces. A lake near Nushergák, the Inglutálik River, and the Kótlo River are noted localities for this ivory".[2]

In 1886 the Geological Survey of Canada acquired from Mr. F. Mercier, who had spent many years as a trader in the Yukon region, a number of bones, tusks, and teeth of the Mammoth. These were chiefly obtained by Mr. Mercier near the mouth of the Tananá River, one of the main feeders of the Yukon on the south side. Mr. J. F. Whiteaves, F.G.S., Palæontologist to the Geological Survey of Canada, has kindly furnished the subjoined note on these remains:—

"In my judgment all the Elephantine remains collected by Mr. Mercier in the Yukon region, and now in our Museum, are clearly *Elephas* (sub-genus *Euelephas*) and not *Mastodon*.

"Four of the specimens collected by Mr. Mercier are perfect molars, essentially similar to those from Burlington Heights, near Hamilton, Ontario, which E. Billings referred to *Elephas Jacksoni* of Briggs and Foster, but which Dr. Falconer subsequently identified with *E. primigenius*, Blumenbach.

"The specific relations of the North American fossil Elephants

[1] 'Zoology of the Voyage of H.M.S. 'Herald,'' (1854) p. 142; Am. Journ. Sci. ser. 2, vol. xix. (1855) p. 132; Annual Report, Geol. Surv. Canada, 1887, p. 41 B.

[2] 'Alaska and its Resources,' 1870, pp. 238, 460, 479; Am. Journ. Sci. ser. 2, vol. xlv. (1868) p. 99.

(as distinguished from Mastodons) are treated of at considerable length in vol. ii. pp. 234–238 of the 'Palæontological Memoirs and Notes of the late Dr. Hugh Falconer,' under the heading 'Synonymy of American Fossil Elephants.'

"It is there stated that there are but two species of fossil Elephant in North America. The first of these is the *Elephas* (*Euelephas*) *primigenius*, Blumenbach, of which *E. Jacksoni*, of Briggs and Foster, and *E. americanus*, Leidy, are synonyms. According to Dr. Falconer, all the specimens from the Yukon, Alaska, and Burlington Heights are *E. primigenius*. The second species is *E. Columbi*, Falconer, of the southern part of the United States and Mexico."

The writer, in 1887, carried out an extended reconnaissance-survey in the Yukon District, in the valleys of the Pelly and Lewes branches of the main stream, but not going below the confluence of these two rivers.[1] In the whole region thus traversed no Mammoth-remains were met with, nor was their presence reported by such of the gold-miners as had worked in parts of these valleys; though some of the same men had frequently noted Mammoth-bones farther down the Yukon valley, particularly in the vicinity of Forty-Mile Creek, where rather important placer-mining has been carried on.

The above notes refer particularly to the occurrence of Mammoth-remains in the inland region of Alaska, and in parts of the adjacent Yukon District of the North-west Territory of Canada—the International boundary following the 141st meridian. The existence of similar remains, as well as those of other animals not now inhabiting the region, has long been known at various places on the coast, both to the south and north of Bering Straits. The most notable and the first discovered of these localities is Kotzebue Sound, where bones were collected by Kotzebue in 1816, Capt. Beechey, of H.M.S. 'Blossom,' in 1826, Capt. Kellett, of H.M.S. 'Herald,' in 1848, Dr. W. H. Dall in 1880, and Mr. Nelson in 1881. The specimens brought back by the three first-named expeditions were described by Eschscholtz, Buckland, Forbes, and Richardson in appendices or auxiliary works to the narratives of the several voyages.

Dall has recently given a summary of what is known respecting these localities, with full references to the published accounts of them.[2] The bones found at Kotzebue Sound and at other places on the coast are associated with what he calls the 'ground-ice formation.' The localities are indicated in a general manner on the map accompanying Dall's work; but, so far as these are described or the writer is aware, no information exists to show that such bones are associated with 'ground-ice' anywhere south of Kotzebue Sound.

The following list of species obtained in Kotzebue Sound is given

[1] Annual Report, Geol. Surv. Canada, 1887–88, Part B.
[2] Bull. U.S. Geol. Survey, no. 84, 1892, pp. 260–267.

by Dall, chiefly from Richardson's report, but with revised nomenclature[1] :—

Elephas primigenius, Blumenbach.
Elephas Columbi, Falconer [?].[2]
Equus major, De Kay.
Alces americanus, Jardine = *Machlis*, Ogilby.
Rangifer Caribou, Baird.
Ovibos moschatus, Blainville.
Ovibos maximus, Richardson = *O. cavifrons*, Leidy.
Bison crassicornis, Richardson = *B. antiquus*, Leidy.

No *Mastodon*-bones appear to have been found in any portion of the extreme north-west of North America.

Of particular interest in connexion with the general question of the distribution of Mammoth-remains in the Alaskan region is the occurrence of such remains (a tooth) on St. George Island of the Pribilof group, in Bering Sea, and on Unalashka Island of the Aleutian Chain.[3] Mr. J. Stanley-Brown further notes the discovery of a Mammoth-tusk on St. Paul Island of the Pribilof group, but appears at the same time to throw doubt on the means by which these remains reached the Pribilof Islands, writing—"As there is not a foot of earth upon either island, save that which has resulted from the decomposition of the native rock and the decay of vegetation, the value of such testimony is questionable."[4]

The precise intention of the cautionary remark just quoted is not clear to the writer. The finding of the bones upon St. George and St. Paul Islands does not appear to be doubtful. Both islands were uninhabited previous to their discovery by the Russians; they show neither traces of glacial action nor erratics; and in what way the Mammoth can be supposed to have reached these islands, except by means of a former connexion with the mainland, it is difficult to understand. We have, moreover, the Mammoth-bones already mentioned on Unalashka Island, vouched for by Dr. Stein, and a like explanation must be found for all these cases. This does not appear to be difficult, for the whole eastern part of Bering Sea is rather notably shallow, nearly everywhere less than 50 fathoms in depth. An elevation of the land by about 300 feet would thus suffice to unite the islands mentioned, with a number of others, to the American Continent, and it appears scarcely to admit of doubt that it was across such a practicable plain that the Mammoth found its way to these places.

The most important observation to be based on the foregoing notes is that the remains of the Mammoth, with those of other associated animals, are, in the north-western part of the North American Continent, abundant in, if not strictly confined to the

[1] *Op. cit.* p. 264.

[2] I have ventured to place a mark of interrogation against this species, for Falconer gives its range as being from Mexico to Georgia and perhaps farther south. See 'Palæontological Memoirs and Notes,' vol. ii. pp. 230–231. See also Howorth, 'The Mammoth and the Flood,' pp. 274–276.

[3] Bull. U.S. Geol. Survey, no. 84, p. 266.

[4] Bull. Geol. Soc. Am. vol. iii. (1892) p. 499.

limits of, a great unglaciated area there existing. With the exception of the southern mountainous sea-margin of Alaska, and doubtless also that of certain local inland ranges, this unglaciated area may be described as comprising nearly the whole of Alaska, together with a considerable portion of the adjacent Yukon District of Canada.

As the result of his explorations in this part of the continent, the writer has been able to determine the fact that during the glacial period the Rocky Mountain or Cordilleran region, from about the 48th to the 63rd degree of latitude North, was at one time buried beneath a great confluent ice-mass some 1200 miles in greatest length in a north-west by south-east bearing, with an average width of about 400 miles.[1]

This Greenland-like ice-cap was distinct from the still greater Laurentide Glacier of Eastern North America, and, because of the trend of the mountain-ranges which it covered, it moved principally in two directions—south-eastward and north-westward. The south-easterly motion of one part of this ice-mass the writer had demonstrated in 1877,[2] but it was not till 1887, and then as a result of the Yukon expedition, that he was enabled to ascertain the north-westerly movement of its northern part, and to show that there was a definite limit to its extent in both directions. Being thus clearly distinct from any extension of polar ice, as well as from the great Laurentide ice-mass, it became appropriate to designate it as the Cordilleran Glacier.[3] Further evidence respecting the northern limit of glaciation in this region has since been obtained by Mr. R. G. McConnell, of the Canadian Geological Survey (1888), Mr. I. C. Russell, of the U. S. Geological Survey (1889), and Mr. C. W. Hayes, of the same Survey (1891).[4] The area covered by, and the directions of movement of, the Cordilleran ice-mass have been approximately mapped in one of the papers above referred to,[5] and the later observations of the above-named gentlemen have not in any material degree changed the indications there given.

Within the area which was covered by the great Cordilleran Glacier, remains of the Mammoth are either entirely wanting or are very scarce. The reported finding of a tooth on the southern part of Vancouver Island, and that of a portion of a large bone (which, though not determinable, may have belonged to such an animal) in gravels worked for gold on Cherry Creek,[6] are the only possible exceptions known to the writer, and the deposits from which the last-mentioned bone was obtained may be of pre-Glacial age.

[1] 'On the later Physiographical Geology of the Rocky Mountain Region in Canada,' Trans. Royal Soc. Canada, vol. viii. (1890) sect. iv. p. 27.

[2] Report of Progress, Geol. Surv. Canada, 1877–78, pp. 136 B, 151 B; Quart. Journ. Geol Soc. vol. xxxiv. (1878) p. 119, vol. xxxvii. (1881) p. 283.

[3] 'American Geologist,' vol. vi. (1890) p. 162.

[4] Annual Report, Geol. Surv. Canada, 1888–89, p. 28 D; Bull. Geol. Soc. Am. vol. i. (1890) p. 144; National Geogr. Mag., Washington, vol. iv. p. 157.

[5] Trans. Royal Soc. Canada, *op. cit.* pl. ii. map no. 4.

[6] Okanagan District, British Columbia.

The likeness of the non-glaciated north-western portion of North America, with its abundant Mammoth-remains, to the similarly characterized northern part of Asia has already been recognized. The purport of the foregoing remarks is to indicate the existence of a south-eastern boundary to the Mammoth-inhabited portion of Alaska and the Yukon District; nor can it be reasonably doubted that the North American and Asiatic land was continuous at the time of the existence of the Mammoth, or for some portion of that time; for an elevation of the land sufficient to enable the Mammoth to reach the islands in Bering Sea, already referred to, would result in the obliteration of Bering Straits.

Many conjectures have been advanced as to the mode of occurrence and origination of the 'ground-ice formation,' in association with which the bones of the Mammoth and other animals are found along the northern coasts of Alaska. Dall summarizes these in his work previously cited,[1] and it may now be confidently assumed that the descriptions of Kotzebue and his party, of Capt. Kellett and others on the 'Herald,' of Dall and Lieut. Cantwell,[2] correctly indicate the facts of the case. The clearest descriptions of the phenomena are those of Seemann and Dall.[3] From these it appears that the lower parts of cliffs which have some extent on Kotzebue Sound are composed of solid ice, somewhat discoloured and impure, and showing indications of stratification. Above this ice rests a layer of clay, in which the bones occur, and capping the whole is a peaty layer supporting the vegetation of the region. It is further apparent that this or a very similar formation occurs at a number of points along the northern coast of Alaska, but nothing has been adduced to show that it is absolutely continuous over any great area;—there is, in fact, some reason to believe that it is confined to limited tracts, even in the vicinity of Kotzebue Sound.[4]

In the present connexion, the 'ground-ice formation' is of interest only in so far as its existence and the mode of its origination may throw light on the date and method of entombment of the Mammoth-remains associated with it. With respect to the origin of the deposits, the writer ventures to offer the following suggestions.

The country in which the 'ground-ice formation' occurs is low in its relief, and the formation occupies its lower tracts. The ice itself must undoubtedly have been produced upon a land-surface, and since the time of its production this surface can never have been covered by the sea; for this would inevitably have reduced the frozen condition of the overlying clays, and have resulted in the destruction of the icy sub-stratum as well.

With an elevation of the land by an amount of 300 feet or more (such as appears to be required by the Mammoth-remains on islands already mentioned) the warmer waters connecting with the Pacific

[1] Bull. U.S. Geol. Survey, No. 84, pp. 260–264.
[2] 'American Geologist,' vol. vi. (1890) p. 51.
[3] 'Voyage of H.M.S. 'Herald,'' vol. ii. pp. 33 *et seqq.*; Bull. U.S. Geol. Surv. No. 84, pp. 261 *et seqq.*
[4] 'American Geologist,' vol. vi. (1890) p. 52.

would be confined to the deeper western portion of what is now Bering Sea, forming there a limited gulf, without outlet to the north, from which the region where the 'ground-ice formation' is now found would be so far removed as to greatly reduce its mean annual temperature. Snow falling upon this nearly level, northern land, and only in part removed during the summer, would naturally tend to accumulate in *nevée*-like masses in the valleys and lower tracts, and the underlying layers of such accumulations would pass into the condition of ice, though without the necessary slope or head to produce moving glaciers. The evidence does not seem to imply that the Mammoth resorted to this extreme northern portion of the region during the actual time of ice-accumulation, but this animal may be supposed to have passed between Asia and America along the southern parts of the wide land-bridge then existing.

At a later date, when the land became depressed to about its present level, Bering Sea extended itself far to the eastward, and Bering Straits were opened. The perennial accumulation of snow upon the lowlands ceased, and in the southern parts of Alaska such masses as had been formed may have been entirely removed. Farther to the north and at a greater distance from the Pacific waters, while the total precipitation would probably be increased, a greater proportion would fall as rain, and floods resulting from this and the melting of snow on the higher tracts would be frequent. Thus it may be supposed that deposits of clay and soil from adjacent highlands and from the overflow of rivers covered large parts of the remaining ice of the lowlands, and that wherever so covered it has since remained; the winter temperature being still sufficiently low to ensure the persistence of a layer of frozen soil between the surface annually thawed and the subjacent ice. Over the new land thus formed the Mammoth and associated animals appear to have roamed and fed, and wherever local areas of decay of the ice may have arisen, bottomless bogs and sink-holes must have been produced which served as veritable traps.

It will be observed that this hypothesis requires a rather abrupt passage from the conditions under which the ice accumulated to those in which, before it had time to disappear, it began to be covered up by soil, but the change may nevertheless have extended over a considerable number of years. The association of the Mammoth with an animal so essentially Arctic as the Musk-Ox requires—as has frequently been pointed out—the admission that the Mammoth was capable of living in a rigorous climate, though it may be that the southern limit of the migration-range of one animal merely overlapped the northern limit of the migration-range of the other. The occurrence of the Moose (*Alces americanus*) implies the existence at that time of woodland, or at least of well-grown thickets.

In the Cordilleran region generally, the Pliocene and Glacial periods were characterized by several important changes in elevation and depression of land;[1] but it is unsafe to assume that these

[1] Trans. Royal Soc. Canada, vol. viii. (1890) sect. iv. p. 54; Bull. U.S. Geol. Survey, no. 84, p. 278.

changes equally affected the northern region here particularly treated of; for it is not only very distant from the localities which have so far been specially studied, but the physical features of the Cordilleran belt become diffuse and ill-marked to the north, and such mountain-ridges as remain assume new trends. It may, however, be taken for granted that this region shared to some extent in these great movements of elevation and depression, and as the very existence of the 'ground-ice' shows that the area where it is found has not since the date of its formation been materially lower than at present, it may reasonably be argued that it dates from a period approaching the conclusion of the series of changes in level, or subsequent to the last well-marked epoch of depression of the land.

Thus, without entering into any details respecting the sequence of these great earth-movements in the Cordilleran region of British Columbia,[1] it may be stated as probable that the uprising of the land which led to the accumulation of the 'ground-ice' was coincident with the second (and latest) epoch of maximum glaciation, which was followed by an important subsidence in British Columbia.

Discussion.

The PRESIDENT said that many interesting points had been brought forward by the Author. The differentiation of the glaciated from the unglaciated area, and the clear recognition of a north-western as well as a south-eastern boundary to the Cordilleran ice-mass, struck him as being of great importance.

Sir HENRY HOWORTH remarked upon the long and careful survey of N.W. America which has been made by the Author, and upon the value of the conclusions to which he has come: firstly, in regard to the absence of ancient glaciation in Alaska and its borders; secondly, in regard to the existence of a great glacier in the Cordilleras, whose products are quite independent of and have nothing to do with the Laurentian drift; and thirdly, in regard to the distribution of the Mammoth. It was a new fact to him, and one of great importance, that Mammoth-remains had occurred in Unalashka and the Pribilof Islands in Bering Sea, proving that in the Mammoth age there was a land-bridge here, as many inquirers had argued. It would be very interesting to have the western frontier defined, where the Mammoth-remains cease to be found. It would also be very interesting to know how far south on the west of the Cordilleras the true Mammoth, as distinguished from *Elephas Columbi*, has occurred.

Regarding one conclusion of Dr. Dawson's, the speaker could not agree with his friend, namely, about the age of the strata of ice sometimes found under the Mammoth-beds in Alaska as they have been found in Siberia. The speaker was of opinion that this ice has accumulated since the beds were laid down, and was not there when the Mammoth roamed about in the forests where he and his com-

[1] For a discussion of which see Trans. Royal Soc. Canada, vol. viii. (1890) sect. iv. pp. 40–55.

panions lived. Humus and soil cannot accumulate upon ice except as a moraine, and there are no traces of moraines or of great surface-glaciation in Alaska and Siberia. Nor could either the flora or fauna of the Mammoth age have survived conditions consistent with the accumulation of these beds of ice almost immediately below the surface, or consistent with their presence there. The speaker considered that these beds are due to the filtration of water in the summer down to the point where there is a stratum of frozen soil, through which it cannot pass and where it consequently accumulates, freezes, raises the ground, and in the next season grows by the same process until a thick bed of ice has been formed. The evidence goes to show that the present is the coldest period known in recent geological times in Siberia and Alaska, and that the period of the Mammoth and its companions was followed and not preceded by an Arctic climate where its remains occur.

Dr. Henry Woodward mentioned that in 1850 Capt. Kellett and Lieut. Wood brought remains of Musk-Ox and Mammoth to the British Museum from Kotzebue Sound, Alaska; and in 1873 the Rev. R. McDonald (one of the Hudson's Bay Company's Chaplains) from Fort McPherson, Mackenzie River, Arctic America, gave to the National Collection, from the Porcupine River, remains of Mammoth, Musk-Ox, *Bison priscus*, and Horse. The *Mastodon* has lately been found in Kent County, Ontario, Canada. These instances prove the former abundance of the land Mammalia in high latitudes in North America. The most interesting point in Dr. Dawson's paper is the mention by him of the remains of Mammoth on the Aleutian Islands, proving that this was the old high road for this and other mammals from Asia into North America in Pleistocene times.

Prof. Hull observed that, with reference to the requirements of the large animals referred to in Dr. Dawson's interesting paper, he had seen it stated that one had been discovered in N.W. America nearly entire, and in its stomach were about seven bushels of vegetable matter. However that might be, it seemed clear that the climate of the circumpolar regions had undergone a great change since the Mammoth had become extinct; in consequence of which the vegetation had materially fallen off. He also desired to call attention to the clear evidence which the Author's paper afforded of the former wider extension of land in the Arctic regions during the Mammoth period.

2. *On the* SEQUENCE *of* PERLITIC *and* SPHERULITIC STRUCTURES: *a* REJOINDER *to* CRITICISM. By FRANK RUTLEY, Esq., F.G.S., Lecturer on Mineralogy in the Royal College of Science, London. (Read November 22nd, 1893.)

[PLATE I.]

IN a paper on 'The Shap Granite and the Associated Igneous and Metamorphic Rocks'[1] the authors, Messrs. Harker and Marr, did me the honour to refer to certain statements made by me in the year 1884[2] with regard to the microscopic structures of a perlitic felsite, associated with the Coniston Limestone where it crosses the northern end of the Long Sleddale Valley in Westmoreland.

The opinion which I then expressed was that "spherules may cause the devitrification of a rock after it has solidified and after perlitic fission has supervened." A list of the structures, present in the section examined, was also given in the following order of sequence:—1. Fluxion-bands. 2. Perlitic structure traversing these bands. 3. Minute spherules constituting the whole rock, so far as spherules can do so,[3] and passing through the perlitic fissures. 4. Subsequent fractures. 5. Formation of quartz-veins along these lines of fracture.

In the following year (1885) I again referred to this rock in one of the Memoirs of the Geological Survey,[4] remarking that "Spherulitic devitrification followed the development of the perlitic structure."

Messrs. Harker and Marr, after alluding to the microscopic drawings of this rock published in Mr. Teall's 'British Petrography' (1888) pl. xxxviii. and to my own remarks, namely those which have just been cited, made the following observation:—"The latter author has expressed the opinion that the spherulitic structure is here an effect of devitrification subsequent to the perlitic cracking; but we are unable to see that he has given any reasons for this view. The practice of assigning a secondary origin to special structures in the older acid lavas has perhaps been pushed to excess in some quarters. In the Westmoreland rhyolites there are traces of perlitic fissures traversing rocks which are now microcrystalline, and other appearances pointing to the alteration of an originally glassy mass; but we find nothing to suggest that the spherulitic and allied structures are of formation posterior to the consolidation of the lava: and the breaking up of the vitreous material of the rocks examined seems to have been in many cases a chemical, not merely a molecular change."

Being averse to controversy, I might have allowed this statement

[1] Quart. Journ. Geol. Soc. vol. xlvii. (1891) p. 303.
[2] *Ibid.* vol. xl. p. 345.
[3] The devitrification of this rock is in some places microcrystalline.
[4] 'The Felsitic Lavas of England and Wales,' p. 13.

to pass unchallenged; but, on casually looking through the pages of the first part of the new edition of Prof. Zirkel's 'Lehrbuch der Petrographie' and finding therein an allusion to Messrs. Harker and Marr's criticism of my views, it seemed incumbent upon me to defend my statements.

Owing to the length of their very admirable paper, it is possible that the particular passage in question was not read at the meeting. Had it been, I should probably have responded during the discussion. The point at issue is, in a certain sense, a small one, since the structures themselves are usually microscopic; but its significance is larger than might, at first sight, appear, since it involves the retention or abolition of an old-established landmark in petrography.

In approaching this particular question we have to consider what a rock once was, as well as what it now is. And, here, a difficulty to which I have often alluded steps in.

We have to distinguish between those rocks in which a micro- or cryptocrystalline structure has been set up prior to, or during consolidation, as in lithoidal rhyolites; and those in which such structure has been developed after consolidation, as in devitrified glassy rhyolites and obsidians.

Among the older rhyolitic rocks there is but one structure, the perlitic, which, when present, affords what has hitherto been regarded as a certain proof that a rock assumed a vitreous character at the time of consolidation. It is a valuable means of diagnosis, which must hold good until it can be proved that perlitic structure can be set up in a rock which already possesses a micro- or a cryptocrystalline structure.

If we examine the more recent rhyolites, and compare those of a vitreous with those of a lithoidal character, we find that the former frequently exhibit a perlitic structure, while in the latter no such structure is ever seen, assuming, of course, that the lithoidal character is not the result of subsequent alteration.

I am unacquainted with a single instance in which this structure has been developed in a recent lithoidal rhyolite, even when the rock is mainly micro- or cryptocrystalline, still less would one expect to find it in a rock essentially composed of small spherulites.

In a section of an obsidian from the Yellowstone, largely composed of minute spherulites traversing the rock in bands, a perlitic structure has been set up in the vitreous portions of the rock, but that it has been developed subsequently to the formation of the spherulites is sufficiently proved by the way in which the perlitic cracks here and there encircle an isolated spherulite and by the manner in which the larger cracks follow the boundaries of the spherulitic bands (Pl. I. fig. 3). In another rock from the Upper Geyser Basin, Madison River, Yellowstone, which is almost wholly composed of small spherulites, there is no evidence whatever of perlitic structure. In another similar rock from the Lower Geyser Basin, perlitic structure is also absent. These are beautifully fresh examples, and should show the structure well if it were present. In

the first of these cases which I have cited the perlitic structure is present only in the vitreous portions of the section, and it has been developed subsequently to the formation of the spherulites. In the fine example of obsidian from Pilas, Jalisco, Mexico, described and figured in the Journal of this Society,[1] the development of the perlitic structure has also followed that of the spherulites. Of this there can be no doubt.

Being anxious to adduce an instance in which the order of succession is reversed, *i. e.* where the spherulitic has succeeded the perlitic structure, a section of perlitic obsidian from Buschbad, near Meissen, was selected. Here in the clearest manner a spherulite or a group of spherulites (Pl. I. fig. 4) may be seen to have formed across a perlitic crack, just as in the devitrified obsidian of Long Sleddale (Pl. I. fig. 2); and that the spherulites in the Meissen rock are devitrification-products there can be no question, since they often follow the perlitic fissures, are irregularly distributed, and do not form streams. A section of a devitrified obsidian from Boulay Bay, Jersey (Pl. I. fig. 5), containing coarse spherulites, shows well-marked perlitic structure in the once vitreous portions, which are now microcrystalline in structure. The boundaries of these microcrystalline grains sometimes abut against the perlitic fissures and at others traverse them. The perlitic was in this case developed before the microcrystalline structure.

Re-examination of sections of the Long Sleddale rock shows me no reason to alter the conclusions at which I formerly arrived, nor do I doubt the value of perlitic structure as a means of recognizing the originally vitreous character of the rock, or of that portion of the rock in which it may happen to occur. Perlitic structure is known to be developed in amorphous bodies, natural and artificial; and in no single instance, so far as I am aware, has it been detected in those which can be proved to have been in a crystalline or microcrystalline condition at the time of consolidation. That the Long Sleddale felsite may vary considerably in structure within a very limited area is extremely probable, and it may be that the specimens collected and examined by Messrs. Harker and Marr differed in some respects from mine. The original section upon which my statements were based is at their disposal and will, I trust, help to demonstrate that perlitic structure is not developed in the spherulitic parts of a vitreous or of a once vitreous rock, but that a spherulitic structure may be superinduced in a rock in which perlitic structure has already been developed. In this case the perlitic structure appears to traverse the spherulites. In reality it is traversed by them. On the other hand, when spherulites have been developed in parts of a vitreous rock and perlitic structure has been set up afterwards, the latter will not transgress the boundaries of the spherulitic areas but will be restricted to the glassy portions of the rock. Finally, cases may occur in which both structures have been simul-

[1] Quart. Journ. Geol. Soc. vol. xlvii. (1891) p. 530.

taneously developed, but I am unable to quote any example in which there is proof of this.[1] The man who can first develop perlitic structure in a crystalline mass will do much to upset what has hitherto been written concerning vitreous rocks. It is to be hoped that experiments in this direction may be tried by those who anticipate successful results.

It is possible that time may show that the views entertained by Messrs. Harker and Marr are correct upon this point, but, in the absence of further evidence, I adhere to my original statements.

EXPLANATION OF PLATE I.

Perlitic and Spherulitic Structures in Vitreous and Devitrified Lavas.

Order of development of structures.	
1st, Perlitic. 2nd, Spherulitic, also in places Microcrystalline.	Fig. 1. Long Sleddale, Westmoreland. Perlitic cracks. × 140. Fig. 2. The same cracks as those shown in fig. 1, but with the positions of three spherulites, as seen between crossed nicols. It is noteworthy that, where these spherulites have been formed across the perlitic fissures, the latter are often barely perceptible, or are completely obliterated. For the sake of clearness the other spherulites and microcrystalline grains, by which the rock is totally devitrified, have been omitted. Had the entire field been represented as filled with spherulites, the point emphasized in the text would not have been apparent.
1st, Spherulitic. 2nd, Perlitic or Synchronous.	Fig. 3. Yellowstone, Montana, U.S.A. Spherulites surrounded by perlitic cracks. These spherulites give a well-defined dark cross in polarized light. × 140.
1st, Perlitic. 2nd, Spherulitic.	Fig. 4. Buschbad, near Meissen. Perlitic cracks traversing spherulites (*s*). The latter are of later formation than the cracks. × 30.
1st, Spherulitic. 2nd, Perlitic. 3rd, Microcrystalline.	Fig. 5. Boulay Bay, Jersey. On the right-hand, perlitic cracks in devitrified obsidian (microcrystalline): on the left, part of a large spherulite (*s*) which is not traversed by the perlitic structure. × 30.

Discussion.

Mr. Marr thanked the Author for the very courteous manner in which he had spoken of his opponents. He was pleased to have elicited this interesting communication from Mr. Rutley, but regretted the absence of his colleague Mr. Harker, which necessitated his making an attempt to reply to the paper. With regard to the Long Sleddale rock, he thought it was simpler to understand perlitic cracks being arrested by spherulites than to suppose that the spherulites formed across and obliterated pre-existing perlitic cracks. The confident way in which the Author had spoken of the Meissen rock seemed to imply that he was, even now, not so confident

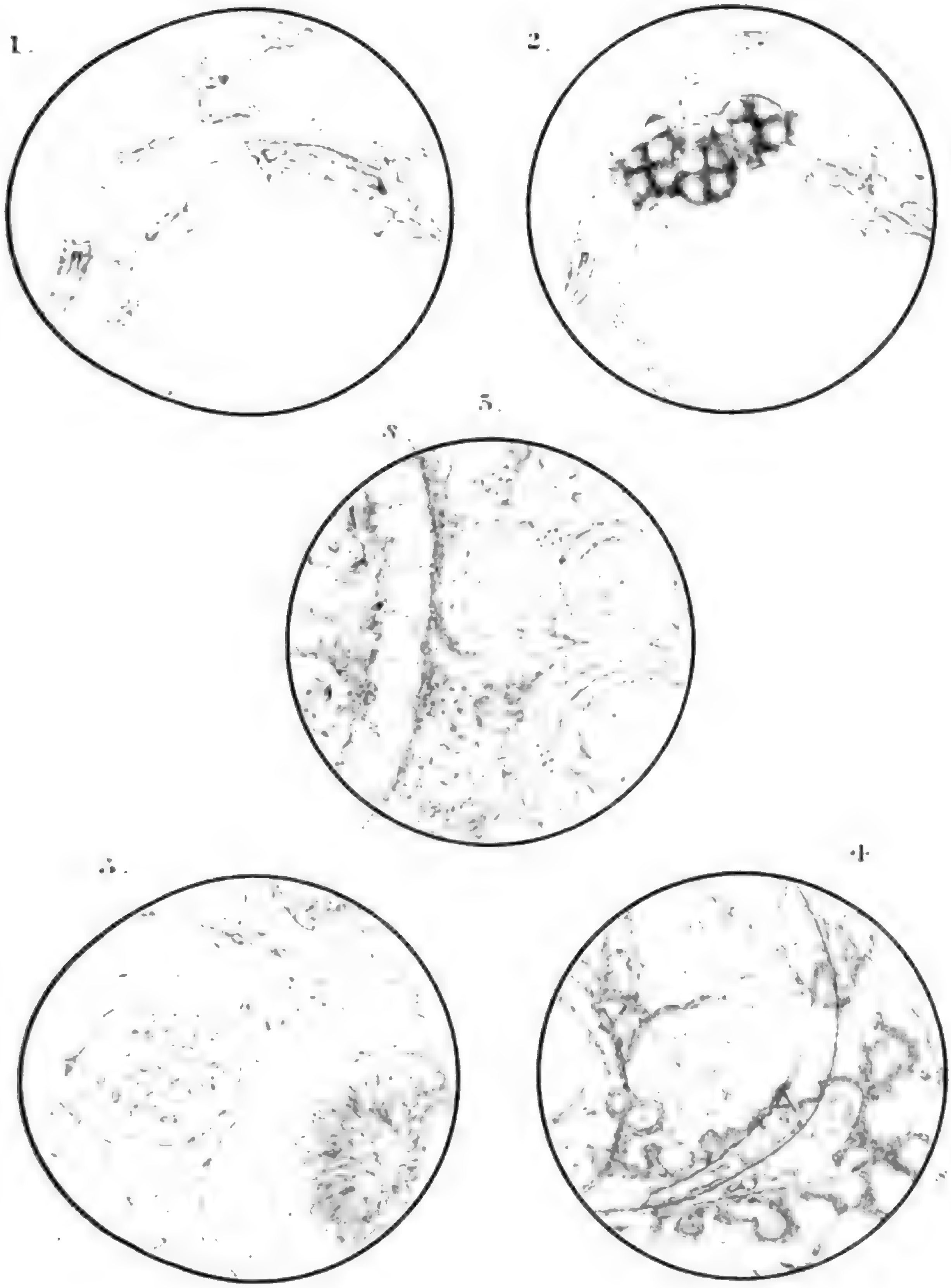
[1] The obsidian from the Yellowstone (Pl. I. fig. 3) *may* possibly have had both structures simultaneously developed.

with respect to that from Long Sleddale. Mr. Harker had informed him (the speaker) that 'giant spherules' occurred with perlitic structure inside; in this case it was difficult to imagine the formation of the spherules subsequent to the consolidation of the rock.

Alluding to Mr. Watts's discovery of a structure resembling perlitic structure in quartz, the speaker deprecated the custom, somewhat rife among geologists, of giving too restricted definitions. If a structure so like perlitic structure as to be practically undistinguishable from it occurred in quartz, it might also occur in other crystalline material.

Dr. J. W. GREGORY was, like Mr. Marr, not satisfied that the spherulites in the Long Sleddale rock were later than the perlitic cracks, as such cracks often end off against solid inclusions in the glassy lava. In the Yellowstone Park cases the spherulites are often old ones in a re-fused lava, and the perlites have bent round them. The figure of the Buschbad case is also not conclusive, as some points in the figure suggested that the perlitic cracks might be the earlier.

The AUTHOR, in reply, again pointed out what he regarded as the order of sequence of the different structures in the rocks described, and alluded to the sections exhibited by Mr. Watts, in which a structure, seemingly perlitic, traversed crystals of quartz. He doubted whether these cracks were really to be regarded as identical with true perlitic structure. In reply to Mr. Marr, he stated that he had never met with any case in which a perlitic fissure was interrupted and abruptly cut off by a previously-formed spherulite, but cited instances in which such fissures accommodated themselves to the surfaces of comparatively large spherulitic bodies. He also briefly replied to Dr. Gregory's remarks.



Frank Rutley del. C. Green lith. Mintern Bros.

PERLITIC & SPHERULITIC STRUCTURES

3. *The* Basic Eruptive Rocks *of* Gran. (A Preliminary Notice.)

By W. C. Brögger, Ord. Professor in Mineralogy and Geology in the University of Christiania, For. Memb. Geol. Soc. (Read November 22nd, 1893.)

Contents.

I. Introduction.

Ever since the beginning of the present century, when the first pioneers in the geological exploration of Norway (Keilhau, Hausmann, Leopold von Buch, and Naumann) investigated the Christiania region, the igneous rocks of that district have been famous as being of more than common interest, as well from the many unique and remarkable rock-varieties as from the exceptionally instructive development of contact-metamorphism produced by the eruptions, and first brought to notice in this region through the observations of Keilhau, Naumann, and Kjerulf.

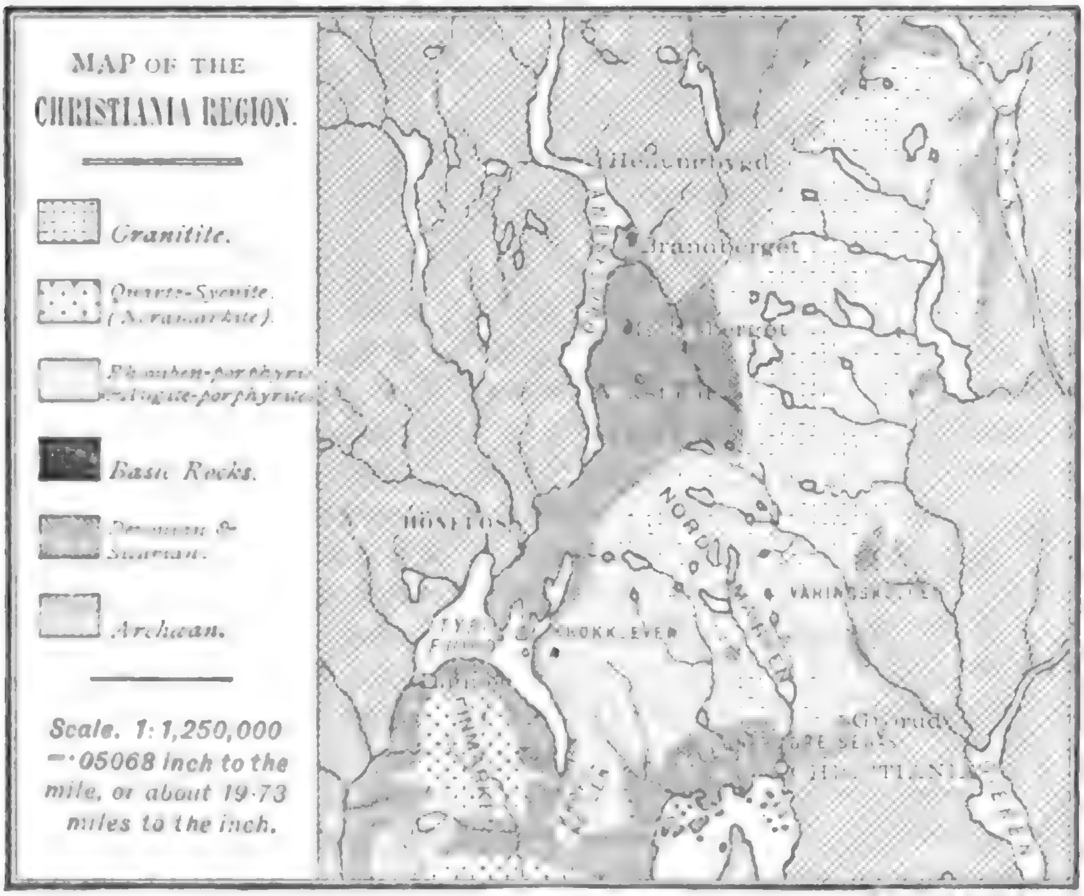
In several preliminary communications[1] on the igneous rocks of the Christiania region I have attempted to prove that all the numerous different masses of eruptive rocks within the sunken district between Lake Mjösen and the Langesundsfjord are genetically connected, and have followed each other in a regular succession; the oldest rocks are the most basic, the youngest (except the unimportant basic dykes of diabase) are the most acid, and between the two extremes I have found a continuous series.

Of late years I have proceeded in a more detailed manner with my investigations of the igneous rocks of the sunken tract of country in the Christiania region. I have not as yet in these studies discovered any facts in contradiction to my previously published observations and the deductions founded thereon. On the contrary, more detailed and minute investigation has only confirmed the correctness of former publications.

[1] 'Ueber die Bildungsgeschichte des Kristianiafjords,' Nyt Mag. for Naturvidenskaberne, vol. xxx. (1886) p. 99. Also, in a detailed address at the meeting of the Association of Scandinavian Naturalists at Christiania, June 1886. A *résumé* was likewise published in my work, 'Die Mineralien der Syenit-Pegmatitgänge der südnorwegischen Augit- und Nephelinsyenite,' Zeitschr. f. Krystallogr. u. Min. vol. xvi. (1890).

I completed in the summer of 1893 a collection of observations for final publication on the oldest basic series of igneous rocks of the Christiania region, and I have now the honour of laying before this learned Society a *résumé* of the most important results of this detailed investigation on the first eruptive series with which the long sequence of volcanic outbursts in the Christiania region commenced in Devonian times.

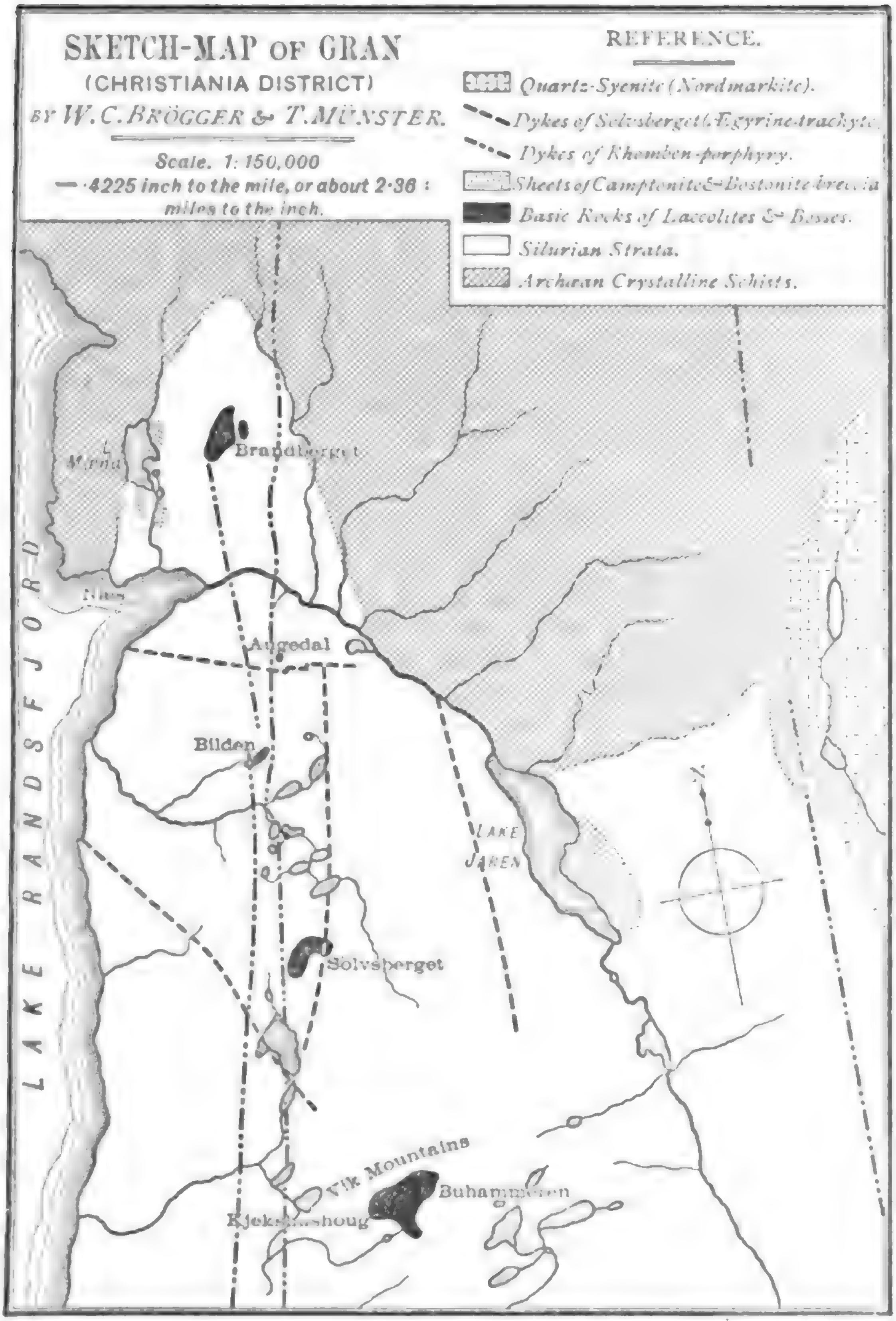
These oldest eruptions have left a series of interesting plutonic rocks in a number of localities in the parish of Gran, between 50 and 60 kilometres (30 to 35 miles) N.N.W. of Christiania, and near Dignæs, on Lake Tyrifjord, about 35 kilometres (22 miles) W.N.W. of Christiania.



The occurrences in Gran are all situated on a great volcanic fissure-line, in an almost north-and-south direction, parallel with the general direction of the neighbouring Lake Randsfjord, the boundary of the sunken tract in that part of the country. The great fault-lines of Randsfjord cut the Archæan mass of land at Næs in a south-south-west to east-north-east direction. Only a few kilometres east of this fault-line we find the fissure of the basic eruptions indicated by a series of mostly dome-shaped hills. In order, from north to south, they run as follows:—

Brandberget (Brandbokampen), 514 metres (1670 feet) above the sea, an imposing hill.

Subsequently there appear several quite small exposures near Augedal, Solberg, and south of Bilden.



Note.—The numerous dykes of camptonite and bostonite are entirely omitted in the above map, because it would be impossible to represent them satisfactorily on so small a scale.

A more considerable occurrence, Sölvsberget, is there met with (9 kilometres or $5\frac{1}{2}$ miles south of Brandberget), a fine eminence, 484 metres (1575 feet) in height.

Four kilometres ($2\frac{1}{2}$ miles) south of Sölvsberget we find the two hills of 'Viksfjeldene' (the Vik mountains), Kjekshushougen and Buhammeren, 537 and 538 metres (1745 & 1749 feet) respectively above the sea-level.

The occurrence at Dignæs, on Lake Tyrifjord, is about 40 kilometres (25 miles) south-west of Buhammeren.

The plutonic rocks in each and all of these localities are closely connected by numerous passage-types, and present a wholly continuous series of basic abyssal rocks. It seems, therefore, impossible to doubt that all these rocks, so closely allied in composition and geological occurrence, have originated from a common source. The limited time at my disposal allows only of a very summary description of the principal varieties.

II. The Olivine-Gabbro-Diabases.

The prevailing kinds of rock in all the greater occurrences (Brandberget, Sölvsberget, Viksfjeldene, and Dignæs) we may characterize as olivine-gabbro-diabases. They are medium- or coarse-grained rocks of granitic structure, often also ophitic; there is not the slightest trace of the ordinary changes met with in regionally metamorphosed gabbro. The mineral composition is, firstly, plagioclase, the constitution of which varies, mainly from Ab_1An_1 to Ab_2An_3, and consequently it belongs to the labradorite series; quite subordinate, a small proportion of orthoclase is also proved to occur in several specimens (in the main rock of Sölvsberget it is very common). Besides the felspar a mineral of the pyroxene group prevails: the common pyroxene in these rocks is a violet, titaniferous, lime-magnesia-pyroxene, with comparatively small amounts of aluminium- and iron-oxides; olivine and a dark reddish-brown biotite (lepidomelane) are both common constituents. An orthorhombic pyroxene (bronzite or hypersthene) is observed in the rock of Sölvsberget, but in very small quantities. Basaltic brown hornblende is rarely present, and then in small quantity. The common iron ores, titanic iron and magnetite, in small amounts, also pyrite, pyrrhotite, and apatite, the last often abundant, make up the rest of the primary components.

A detailed petrographical description of the varieties of the olivine-gabbro-diabase in the different localities, and, still more, a thorough study of all the facies-types, would carry us too far. I shall therefore, on this occasion, confine myself to pointing out the important circumstance that *the prevailing rocks in the different exposures along the fissure clearly change their character in a regular manner from north to south. On the whole, the average basicity of the prevalent rocks can be proved to decrease in that direction.*

In the northernmost locality, Brandberget, the prevailing rock is a very basic olivine-gabbro-diabase, so poor in felspar that it passes into pyroxenite. Jointly with this predominant rock there occur also, to a great extent, typical pyroxenites, often of very coarse grain, besides coarsely radiated hornblendite (with the hornblende-prisms measuring as much as 10 centimetres or 4 inches in length), the latter rather subordinate, and also subordinated hornblende-bearing gabbro-proterobases and other rocks with brown basaltic hornblende. These basic rocks (the pyroxenite, the hornblendite, and the gabbro-proterobase) are traversed by innumerable segregation-veins of a fine-grained augite-diorite or augite-syenite (akerite), which will be further referred to a little later on.

Moreover, in the small exposures of Augedal, Solberg, and Bilden, very basic varieties—pyroxenites combined with camptonites—prevail.

On the top of Sölvsberget a more acid olivine-gabbro-diabase is already the prevalent rock; pyroxenites and other basic rocks are there only observed as rather subordinate contact-facies.

We find the same conditions in the Viksfjeldene, where also more acid segregation-veins of augite-diorite, etc., are widely spread.

The most acid rock is represented in the occurrence at Dignæs; the ultrabasic types are entirely wanting here, the predominant rock being an olivine-gabbro-diabase rich in felspar.

The following analyses (Table I.) serve to illustrate the successive changes in the chemical composition of the prevalent kinds of rock from north to south:—

Table I.

	I.	II.	III.
SiO_2	43·65	47·00	49·25
TiO_2	4·00	2·30	1·41
Al_2O_3	11·48	15·20	16·97
Fe_2O_3	6·32	5·69	15·21
FeO	8·00	6·59	
MnO	Trace	0·26	Trace
MgO	7·92	8·76	abt. 3·00
CaO	14·00	12·60	7·17
Na_2O	2·28	1·45	4·91
K_2O	1·51	0·66	2·01
H_2O	1·00	0·30	abt. 0·30
P_2O_5	Trace	Trace	0·76
$CaCO_3$	Trace	......	Trace
	100·16	100·81	abt. 100·99

I. Olivine-gabbro-diabase of Brandberget; analysis by L. Schmelck.
II. Do. of Sölvsberget; analysis by Sårnström, the alkalies determined by L. Schmelck.
III. Do. of Dignæs; analysis by A. Damm, the alkalies determined by L. Schmelck.

According to an approximate calculation from the above analyses, the mineral composition per cent. may be estimated as follows:—

TABLE II.

	I. *Brandberget.*	II. *Sölvsberget.*	III. *Dignæs.*
Felspars	about 12	about 46	about 64
Pyroxene	69	26	10
Olivine	5	12½	9
Biotite	3	9½	8½
Iron Ores	7	5	6½
Apatite, serpentine, chlorite, etc. ...	4	1	2
	100	100	100

The average composition of the three principal varieties of olivine-gabbro-diabase, the iron being calculated as Fe_2O_3 (all analyses calculated free from water, and finally equalized by reducing them to 100 per cent.), is as follows:—

SiO_2	46·48
TiO_2	2·56
Al_2O_3	14·50
Fe_2O_3	14·44
MgO	6·54
CaO	11·23
Na_2O	2·87
K_2O	1·38
	100·00

The olivine-gabbro-diabase of Sölvsberget, as will be thus seen, differs only slightly in composition from the average rock.

The rocks in the northern occurrences of these oldest eruptions in the Christiania region are then, as we have seen, mainly pyroxenic rocks of a basic character, while the southern localities along the same fissure show chiefly felspathic rocks of somewhat greater acidity. Probably the average composition of all the masses of rock in Brandberget differs only slightly from the above-calculated average; on the other hand, it is certain that the average composition of the rocks from Dignæs is more acid than this average. We have, therefore, here a remarkable example of the differentiation of a molten magma in a regular manner *in horizontal direction* along connected fissure-lines. Nor is it the only case of its kind in the Christiania region.

With respect to the geological appearance of these abyssal rocks, I will simply remark that they are only partially of a laccolitic character; as a rule they are enveloped as vertical bosses, the contact-plane often cutting the adjacent Silurian strata.

The small exposure south of Bilden is, on the whole, an inclined laccolitic sheet, the rocks in the same chiefly showing a porphyritic structure and the composition of the camptonite-group, and being only to a slight extent crystallized as pyroxenites. On the Viksfjeldene also the laccolitic character is evident.

As an example of partly laccolitic bosses we will take the case of Sölvsberget.

Sölvsberget is a roof-shaped hill, about 1·5 kilometre (1 mile) in length from north to south, and about 1 kilometre ($\frac{5}{8}$ mile) in width from west to east; the top is elevated about 250 metres (813 feet) above the surrounding country; the eastern side is very abrupt, the western side more gradually sloping. In its northern and southern parts Sölvsberget is formed of Silurian (Ordovician) strata of étages $4\ a\ \alpha$ and $4\ a\ \beta$ (shales with *Ogygia dilatata*, Brünn, and *Ampyx*-limestone); the main strike is west to east, or west-north-west to east-south-east, the dip generally showing angles varying from 50° to 80°. The central part of the hill is occupied by the eruptive rocks; on the map it will be seen that their surface, in horizontal projection, has a boomerang-like shape; in the south-western part the strata are vertically traversed by the plutonic rock; in the middle of the 'boomerang' the eruptive rock appears to be conformably injected between the shales; but in the eastern part the eruptive surface suddenly sinks to a lower level, and seems there partly to be of a laccolitic character. The whole surface occupied by the plutonic rocks is only 0·3 square kilometre (75 acres).

III. The Effects of Contact-metamorphism by the Olivine-Gabbro-Diabase.

In all occurrences of these plutonic rocks we find a typical abyssal contact-metamorphism, the peripheric extent of which depends on the size of the plutonic masses in the different localities. At Sölvsberget the alteration of the Silurian strata is perceptible at distances of 200 or even 300 metres (220 or 330 yards) from the boundary on the eastern side of the hill, where the strikes of the stratified rocks and of the eruptive boss run in nearly the same direction; in the south-east the observed alterations terminate much nearer to the eruptive rock.

The unaltered rocks of Sölvsberget are the common, black to dark grey, argillaceous shales of étage $4\ a\ \alpha$ (*Ogygia*-shales), with a few interbedded lenticular masses of limestone. By the contact-metamorphism the shales, as usual, are altered into dark violet hornstones, shimmering, as we get closer to the boundary, more and more from innumerable small scales of mica, the diameter of which close to the boundary attains several millimetres. In the next zone of alteration the hornstone is macroscopically crystalline, with a grain of medium size, often possessing a very remarkable porphyritic structure, due to crystals of plagioclase more than 5 millimetres ($\frac{1}{5}$ inch) long. The limestone-lenses are altered into calcareous hornstone (*kalksilikat-hornfels*).

The contact-metamorphism along the boundary of the olivine-gabbro-diabases of Gran is mainly of interest, because the microscopical observations on the altered rocks make it very probable that the previous supposition, as to the independence of the alteration in regard to the composition of the plutonic rock itself,

can be proved to be incorrect. I had myself believed till now that contact-metamorphism in strata of the same nature, by otherwise identical conditions, has generally given rise to the same alteration-products—without regard to the 'chemical quality' of the eruptive rock in question. The development of the contact-metamorphism in Gran seems now to prove that this opinion was erroneous.

The short time at my disposal does not allow of a detailed description of all the observations upon which I found my altered opinion. I shall only mention a single fact.

Along the boundary of the basic plutonic rocks of Gran, all of which are comparatively rich in magnesia and iron oxides, the more highly altered hornstones of the *Ogygia*-shales show an essential percentage of hypersthene. I had previously mistaken the mineral for andalusite; it occurs as innumerable small prismatic crystals, but is easily distinguished by its optical characters. To make assurance doubly sure, I have, with considerable difficulty, isolated a small portion of the hypersthene, and have had it analysed by Herr L. Schmelck. The analysis gave:—

SiO_2	48·10
FeO	22·28
MgO	21·83
CaO	2·20
	94·41

The loss is due to a mishap in the course of determination of the silicic acid; adding 5·56 per cent. SiO_2, the above analysis agrees exactly with the composition of an hypersthene, in which the molecular proportions are

$$FeO : (MgO, CaO) = 1 : 2.$$

Now the very same strata of the *Ogygia*-shales, 7 kilometres ($4\frac{1}{3}$ miles) east of Sölvsberget, are altered into hornstones by the influence of the immense masses of quartz-syenite (nordmarkite) extending over the whole district between Gran and Christiania. I have examined a number of specimens of these hornstones from Rånåsen and other localities. In none of them have I discovered the slightest vestige of hypersthene. As is well known, hypersthene or orthorhombic pyroxene is, upon the whole, never observed to have been produced by contact-metamorphism alongside abyssal rocks.

It seems, therefore, that in this case the basic magma of the olivine-gabbro-diabase, as compared with the acid magma of the quartz-syenite, must have influenced, in a peculiar manner, the argillaceous shales of étage 4 *a a* by altering them into hypersthene-bearing hornstones. Whether this special influence is due to a transfer of magnesia and ferrous oxide from the magma, or not, is a problem which can only be settled by a series of analyses as yet unfinished.

In other respects, too, the contact-metamorphism alongside the above-described basic rocks is of interest; but, as this question is

apart from my main subject, I must defer observations in connexion therewith to another occasion.

The small and insignificant basic abyssal masses of Gran are not in themselves of sufficient importance to justify me in occupying the time of this Society by describing them. There are, however, other circumstances, not as yet referred to, which give them great interest. They are accompanied by a great series of dykes and sheets, the study of which throws much light on those processes of differentiation which are just at present being made the object of thorough research by petrologists and geologists.

IV. The Camptonites and Bostonites.

Along both sides of the entire fissure-line on which the abyssal rocks are situated, we find an innumerable multitude of dykes and sheets of camptonite and bostonite, two kinds of rock which have formerly been admitted to be closely associated with masses of nepheline-syenite.

Camptonite (lamprophyric dyke-rock essentially composed of basic plagioclase and brown basaltic hornblende, often porphyritic from phenocrysts of the latter mineral) has been previously described from Campton Falls in New Hampshire [1]; Montreal in Canada [2]; Forest of Dean in Orange Co., N. Y.[3]; Fort Montgomery (Fairhaven, Proctor, etc.) in the Hudson River Highlands [4]; Whitehall in Washington Co., N. Y.[5]; Lake Champlain Valley [6]; nearly allied rocks, though hardly typical camptonites, are described from Val Avisio in the Tyrol [7]; Inchnadampf in the Scottish Highlands [8]; Waldmichelbach and other localities in the Spessart.[9]

The name 'bostonite' was introduced by Rosenbusch and applied to dyke-rocks with trachytic structure, essentially composed of felspars without dark minerals; a more detailed description is given by Kemp. Bostonites are known from Marblehead near Boston,[10] Montreal in Canada,[10] Serra de Tingua in Brazil,[11] and from Lake Champlain Valley.[12] In all previously described occurrences the bostonites are connected with different basic dyke-rocks, and with masses of nepheline-syenite (?) in the vicinity; among the associated basic rocks near Montreal and Lake Champlain there are also camptonites.

[1] G. W. Hawes, Am. Journ. Sci. ser. 3, vol. xvii. (1879) p. 147.
[2] B. J. Harrington, Geol. Surv. of Canada, Report for 1877–78 G, p. 42.
[3] J. F. Kemp, Am. Journ. Sci. ser. 3, vol. xxxv. (1888) p. 331.
[4] *Id.* 'Amer. Naturalist' for 1888, p. 691.
[5] *Id.* and V. F. Marsters, 'Amer. Geologist,' vol. iv. (1889) p. 97.
[6] J. F. Kemp and V. F. Marsters, Trans. N. Y. Acad. Sci. vol. xi. (1891) p. 13.
[7] Corn. Dölter, Tschermak's Min. Mitth. (1875) pp. 179, 180, 304; A. Cathrein, Zeitschr. f. Krystallogr. u. Min. vol. viii. (1884) p. 221.
[8] J. J. H. Teall, Geol. Mag. for 1886, p. 346.
[9] Erw. Goller, Inaug. Diss. (Strassburg, 1889).
[10] On literature, see Kemp and Marsters, *op. supra cit.* p. 17.
[11] M. Hunter and H. Rosenbusch, Tschermak's Min. u. Petr. Mitth. vol. xi. (1890) p. 445.
[12] Kemp and Marsters, *op. supra cit.*

In the parishes of Gran, Hole, Modum, etc., in the Christiania region, these rock-varieties are exceedingly abundant; they appear partly as vertical dykes, generally with a north-and-south or north-north-east and south-south-west strike, parallel to the main strike of the fissures, on which the bosses of olivine-gabbro-diabase and other basic abyssal rocks are situated, along the lines Brandberget-Sölvsberget and Buhammeren-Dignæs. In one part they are also arranged as intrusive sheets introduced between the Silurian strata, chiefly close to the surface of the Archæan schists, especially in étages 1 and 2, also in 3 and 4, and less often in the higher étages.

Although the surface in Gran is somewhat obscured, several hundred occurrences, of dykes as well as sheets of camptonite and bostonite, have been observed. As an example of the frequency of the dykes, I may mention that in one area alone (along the Melbostad and Helgum road) I counted more than 50 dykes in 1½ kilometre (1 mile); the total thickness of these dykes I measured to be 70 metres (227 feet), that is 1 metre of dyke-mass in every 20. The thickness of the dykes is commonly ½ to 2 metres (1½ to 6½ feet); it seldom attains 5 or 10 metres (16 or 32 feet).

The thickness of the sheets is usually also 1 to 2 metres, less often 10 metres or more; however, a great number of intrusive sheets often follow upon each other, which is the reason why the total thickness in several localities may amount to 20 and even 30 metres (65½ to about 100 feet).

In the vicinity of Brandberget the magma has in preference been intruded as sheets between the planes of the stratified rocks; in the neighbourhood of Sölvsberget, on the contrary, vertical dykes are more prevalent; perhaps this circumstance can be explained by the fact that at Sölvsberget we find only higher étages (such as étage 4) represented.

The camptonites and the bostonites are very intimately connected with each other, and also with the above-mentioned boss-rocks. These connexions are proved by the following facts:—

Firstly, as regards the relation between the bostonites and the camptonites, we may observe that they everywhere appear together in close companionship. Thus, we find innumerable examples of vertical camptonite-dykes associated with immediately adjacent parallel dykes of bostonite; often the same dyke-fissure contains both bostonite and camptonite, and with equal frequency it happens that both rocks appear together as intrusive sheets.

In many bostonite-sheets and dykes we find phenocrysts of brown hornblende, which is the chief mineral among the phenocrysts of the camptonites. I have moreover observed several examples of dykes or sheets in which the centre is bostonite, the sides camptonite, or *vice versâ*. Finally, I have also, but less frequently, observed intermediate kinds between camptonite and bostonite.

Secondly, as to the relation between the eugranitic boss-rocks, on the one hand, and the dyke- and sheet-rocks on the other, we may remark that in Gran and the surrounding parishes the bostonites and camptonites are represented in many hundred dykes and sheets

in the neighbourhood of the above-mentioned basic boss-rocks, whereas other kinds of dykes appear very seldom. I have observed only a small number of rhomben-porphyries (plagioclase-rhomben-porphyry and common rhomben-porphyry, 7 or 8 great dykes partly followed along a stretch of more than 20 kilometres = 12½ miles), mica-syenite-porphyry and ægyrine-syenite-porphyry (Sölvsberget), 8 to 10 greater dykes; finally, a number of diabase-dykes, etc. On the other hand, the dykes and sheets of bostonite and camptonite outside this tract, in which the basic boss-rocks occur, are very sparsely distributed in the Christiania region, and not in the same typical varieties as in Gran parish.

On Brandberget a hornblende-bearing rock, closely allied to camptonite, locally appears as an unquestionable contact-facies of the olivine-gabbro-diabase.

In the small laccolitic sheet south of Bilden camptonite is the main rock; pyroxenite appears here only subordinate and mostly in the central parts; and all the passage-types between camptonite and pyroxenite are found. At Sölvsberget also I have collected a rock of the camptonite-bostonite series, an intermediate type between both extremes, occurring locally as a contact-facies.

The above observations conclusively prove that the camptonites and the bostonites are nearly connected with, and must be derived from, the same magma as the previously-described boss-rocks.

The mutual relation of age between the camptonites and the bostonites is invariably as follows:—

When dykes of bostonite and camptonite cut each other, the former, without exception, is the younger.

In a bostonite (from Lindberget, on Lake Mæna) I have found rounded enclosures of basic masses partly of camptonite, partly of pyroxenite; these enclosures can only be explained as early crystallizations of basic composition in a magma, from which the distinct magma of the bostonite was not yet separated as a final product of the differentiation.

In seven different localities (chiefly in Næs, south-west of Brandberget) there appear considerable sheets of bostonite-breccia; the main localities of these breccias in Næs are situated on the continuation of the great fault-fissures of Lake Randsfjord, and farther north-north-east continued in the fault-crevice along the bed of the Huns river. The breccias are brimful of angular fragments of Archæan schists and Silurian slates (chiefly alum-shales) and limestones of the lowest étages (1–3), all the fragments being cemented by a bostonite groundmass. In several blocks of this breccia I have observed that every fragment is surrounded by a more basic dark-green mass, partly of camptonitic composition; this basic matter, enveloping the angular fragments, is then itself embedded in the scarce bostonitic groundmass. In a similar breccia from Augedal I found a rounded lenticular mass of camptonitic rock ⅓ metre (13 inches) in diameter; this mass showed, on chemical analysis, an undoubted camptonitic composition.

V. Their Origin by Differentiation.

The above-mentioned relations prove, in my opinion, that the common magma, from which the basic bosses along the lines Brandberget-Sölvsberget-Viksfjeldene-Dignæs are crystallized as olivine-gabbro-diabases and pyroxenites, etc., must have been the same magma as that from which the innumerable dykes and sheets of camptonite and bostonite are derived; and further, that all these dykes and sheets have arisen as the result of a differentiation in the original magma, in such a manner that first a basic portion, corresponding with the camptonitic magma, has been separated out by diffusion, and, subsequently, the remaining more acid magma has furnished the material for the bostonite-dykes and sheets.

If these views be correct, the chemical analyses of the different kinds of rock should give undoubted proofs of the process of differentiation in the original magma; and, in my opinion, they do so.

The calculated average composition derived from the three analyses of the olivine-gabbro-diabases of Brandberget, Sölvsberget, and Dignæs probably indicates very closely the average composition of the original basic magma, which was pressed up during the oldest magma-eruptions in the Christiania region, along the western boundary of the sunken tract. By differentiation in a magma of this composition the separate magmas of the camptonite-, and the subsequent bostonite-eruptions, must have been formed.

I have now caused a series of chemical analyses to be made of camptonites and bostonites from one and the same locality, from both sides of Brandberget: of camptonite from Lindberget on Lake Mæna, at the western base of Brandberget, and from Egge on the south-eastern side; also of bostonite from the same 'cutting' as the analysed camptonite. These analyses (by L. Schmelck) have yielded the following result:—

Table III.

	IV. *Camptonite, Mæna.*	V. *Camptonite, Egge.*	VI. *Bostonite, Mæna.*
SiO_2	40·60	42·05	56·50
TiO_2	4·20	5·60	0·85
Al_2O_3	12·55	12·30	18·14
Fe_2O_3	5·47	3·81	3·12
FeO	9·52	9·52	2·86
MgO	8·96	4·83	1·22
CaO	10·80	11·55	3·38
Na_2O	2·54	2·18	5·28
K_2O	1·19	1·11	1·60
CO_2	2·68	2·68	5·11
H_2O	2·28	2·88	1·26
	100·79	98·51	99·32

All these rocks are from sheets; they are, on the whole, rich in carbonates. Calculating the substances free from water and carbonic acid at 100 per cent. (the iron as Fe_2O_3), we get:—

TABLE IV.

	IV a. *Camptonite, Mæna.*	V a. *Camptonite, Egge.*	*Average of* IV a & V a.	*Average of eight Camptonite Analyses.*
SiO_2	41·90	44·73	43·31	43·65
TiO_2	4·34	5·95	5·14	4·63
Al_2O_3	12·94	13·08	13·01	16·29
Fe_2O_3	16·57	15·32	15·94	14·76
MgO	9·25	5·14	7·23	5·96
CaO	11·14	12·29	11·71	10·16
Na_2O	2·62	2·32	2·46	3·05
K_2O	1·24	1·17	1·20	1·50
	100·00	100·00	100·00	100·00

In Table IV., parallel with the average of the camptonite analyses from Mæna and Egge, is placed the calculated average of eight different camptonite analyses (from Campton Falls, Montreal, Fairhaven, Proctor, Fort Montgomery, Mæna, Egge, Hougen); and, as will be seen, the differences are not great.

The following table (V.) shows the bostonite analysis from Mæna, calculated in the same manner; for comparison I have calculated the average of two American bostonite analyses (from Shelburne Point and Champlain Valley) published by J. F. Kemp (*loc. supra cit.*). It will be noticed that the American bostonites are richer in potash than the Norwegian.

TABLE V.

	VI a. *Bostonite, Mæna.*	*Average of two American Bostonite Analyses.*
SiO_2	60·57	60·73
TiO_2	0·91	......
Al_2O_3	19·45	21·00
Fe_2O_3	6·76	3·83
MgO	1·31	0·79
CaO	3·62	4·44
Na_2O	5·66	4·52
K_2O	1·72	4·69
	100·00	100·00

A simple calculation founded on the above data shows that a mixture of 9 parts of the calculated average of the camptonites from Mæna and Egge, and 2 parts of the bostonite from Mæna, would make a composition differing very little from the above calculated (p. 20) average composition of the olivine-gabbro-diabases from Brandberget, Sölvsberget, and Dignæs.

TABLE VI.

	Average of Analyses of *Camptonite & Bostonite.*	*Olivine-Gabbro-Diabase.*	*Difference.*
SiO_2	46·45	46·48	−0·03
TiO_2	4·37	2·56	+1·81
Al_2O_3	14·18	14·50	−0·32
Fe_2O_3	14·27	14·44	−0·17
MgO	6·15	6·54	−0·39
CaO	10·24	11·23	−0·99
Na_2O	3·04	2·87	+0·17
K_2O	1·30	1·38	−0·08
	100·00	100·00	

I am well aware that every calculation of this kind must agree very accurately with actual fact if any importance is to be attached to it; the calculations of rock-compositions as the results of mixtures of a basaltic and a trachytic magma, according to the law enunciated by Bunsen some forty years ago, are in this connexion warning examples. In our case the accordance is very close in all the components, except the titanic oxide and the lime. With respect to the former, I may remark that its percentage varies between wide limits as well in the camptonites as in the olivine-gabbro-diabases. In the camptonites from Mæna and Egge the percentage of titanic oxide is greater than usual, but in the average of the olivine-gabbro-diabases the small proportion of titanic oxide in the rock from Dignæs (see p. 19) lowers the average percentage somewhat considerably. As to the lime, it must be observed that in the olivine-gabbro-diabases the indicated percentage represents the whole of the lime originally saturated with silica; while, in the average of the camptonites and the bostonites, the lime percentage is calculated in rocks from which, by abundant carbonatizing, a portion of the lime originally present has probably been carried away.

These circumstances being taken into account, I am of opinion that the accordance is sufficient; such an agreement cannot be accidental. I think, therefore, I have sufficiently proved that the camptonites and bostonites in Gran have been produced by differentiation of an original common magma, whose *chemical* composition agreed with the average composition of the olivine-gabbro-diabases on the volcanic fissure-lines between Brandberget and Dignæs.

This differentiation can further be proved to have taken place in a liquid magma, even before crystallization of any importance had begun. This appears evident from the striking difference in the *mineral* composition of the olivine-gabbro-diabases on the one hand, and the camptonites and bostonites on the other. In the former, among the minerals—that is, among the first crystallized constituents—pyroxene, olivine, and dark biotite are prevalent, brown hornblende wanting as a rule, or quite subordinate. In the camptonites, on the contrary, the predominant dark mineral is always brown basaltic hornblende, often amounting to more than

60 per cent. of the rock, while olivine and brown mica are often wanting, and pyroxene is invariably subordinate.

We have consequently in the basic rocks of Gran a remarkable example of the fact that one and the same magma *partly* without essential differentiation has been pressed up to a higher level, and there has crystallized out as large boss-masses (in the form of olivine-gabbro-diabase), *partly* has been differentiated at a deeper-seated level into a basic magma (which by its outburst has formed sheets and dykes with porphyritic structure: camptonites), and into a more acid residuary magma (which in the final eruptions has given rise to sheets and dykes of bostonite). This differentiation (into camptonites and bostonites) has partly also taken place in the dyke and sheet-fissures themselves *after* passing up into a higher level.

In order to explain this fact, that one and the same magma has in part been differentiated, in part not, it seems, in my opinion, necessary to assume that *in the latter case the essential cooling of the magma has first taken place in the bosses themselves; while, in the former case, even before the final pressing-up of the magma, an essential decrease of temperature and pressure along the contact-plane of the magma must have taken place in the magma-reservoir.* In this cooling and diminishing of the pressure the magma must have been subject to conditions necessary for producing a tendency to crystallization of the brown basaltic hornblende, although in all probability actual crystallization did not take place. Along the contact-plane there must then have been concentrated by diffusion a liquid stratum essentially containing the components of the brown hornblende. This may be deduced from the fact that the composition of the camptonite derived from this differentiated magma differs but slightly from the probable composition of the brown hornblende,[1] and from the other fact that brown hornblende is actually the essential mineral of the camptonites. These facts then favour the

[1] The analysis of the brown hornblende in the camptonites of Gran is not yet completed. The difference between that and the composition of the camptonite-hornblende published by Hawes is probably unimportant. I refer, therefore, provisionally to his analysis for comparison with the average camptonite-composition:—

TABLE VII.

	Average of ten Analyses of Basaltic Hornblende.	*Camptonite-Hornblende (after Hawes).*	*Average of eight Analyses of Camptonite.*
SiO_2	39·88	40·79	43·65
TiO_2	4·86	(not determined)	4·63
Al_2O_3	14·83	17·36	16·29
Fe_2O_3	12·60	20·85	14·76
MgO	12·27	6·97	5·96
CaO	12·68	10·83	10·16
K_2O ... / Na_2O ...	3·39	4·17 (diff.)	4·55
	100·51	100·97	100·00

The average of 10 analyses of basaltic hornblende is calculated from those published by Schneider, Zeitschr. f. Krystallogr. u. Min. vol. xviii. (1891) p. 579.

belief that the differentiation of the original magma has, to an essential degree, been dependent on the laws which govern the sequence of crystallization, an opinion already maintained by the author several years ago (1886), and further sustained, chiefly here in England, by Teall.

The most easily crystallizable compounds (the least soluble) of the magma have in the diffusion first accumulated along the cooling margin. In the liquid magma itself the different compounds were probably dissociated, but the degree of dissociation most probably decreased with diminution of temperature and pressure. Along the cooling margin of the magma a concentration of dissociated compounds to less dissociated groups has thus taken place, a concentration probably governed by the laws of chemical affinity (see the views of J. H. L. Vogt). These compounds (not identical with the '*kerne*' of H. Rosenbusch) concentrated by the diffusion of the less soluble and more easily crystallizable substances, under the stated conditions along the contact-margin of the magma, have then still been liquid or at least been liquid in the main. In the camptonites and the bostonites the consolidation evidently first began after the outburst of the magma into the fissures, which it has filled up.

The opinion that the most easily crystallizable compounds have diffused to the cooler portion of the magma and there have generated a magma-stratum of peculiar composition has been doubted on the grounds that the rock crystallized after the eruption does not show a stoichiometric composition[1]; however, it seems quite probable that this objection is not decisive. That, in the case in question, the camptonite-magma differentiated from the olivine-gabbro-diabase-magma has not exactly the same composition as brown hornblende, finds a natural explanation in the fact that the spaces of crystallization for minerals which *can* crystallize out of a magma of given composition are well known to partly cover and transgress each other. A diffusion of the compounds of the brown hornblende, to the cooler margin of a magma of the composition above supposed, could not therefore have formed a magma of a pure hornblendic mixture, but only such a composition mixed with an addition of other compounds in subordinate quantities. This admixture is, however, in our case not of any great importance. Then we also find—agreeing with the fact that the felspar in the camptonites crystallized as a rule *after* the hornblende—that the residuary bostonite-magma after the differentiation of the camptonite-magma (setting aside the unimportant percentage of magnesia, iron oxides, and titanic oxide) shows an almost felspathic composition of medium acidity.

I think I have proved that the camptonites and bostonites in Gran have been differentiated from a magma of the average composition of the olivine-gabbro-diabases which appear in the same tract. If the above-explained hypothesis be admitted, this fact seems not to be at variance with the observations from other countries,

[1] Iddings, 'On the Origin of Igneous Rocks,' Bull. Phil. Soc. Washington, vol. xii. (1892) pp. 89–214.

that the above-mentioned kinds of rock are otherwise connected with nepheline-syenites. With the '*kern*' hypothesis of Rosenbusch, on the other hand, the above proved connexion does not seem to agree.

[*Note.*—For rock-types, differentiated out of a common magma, I propose the name 'complementary rocks'; camptonites and bostonites are, then, such complementary rocks. Between the dyke-rocks we have also a number of other examples.

Complementary rocks should, therefore, in the classification of rocks be placed in that rock-group which has a chemical composition agreeing with the composition of the original common magma of the complementary rocks; minettes and aplites, for instance, are complementary rocks of the granite-family, and so on.—Dec. 30th, 1893.]

VI. Differentiation in the Bosses.

The differentiation of the olivine-gabbro-diabase magma into camptonites and bostonites is not the only one which has taken place in this magma. In the boss of Brandberget we find that the same or a very closely allied magma has, by differentiation under other conditions, given rise here to other products. It is true that a magma of hornblendic composition (partly crystallized as pure hornblendite, partly as a camptonitic rock) was differentiated out from the original magma; but these masses are here quite unimportant. The conditions here have evidently not permitted to any great extent the crystallization of dark aluminiferous minerals, such as brown hornblende; consequently the differentiation of the magma has not allowed the concentration of liquid compounds of analogous composition along the margins of the boss. On the other hand, it seems clear that the ruling conditions have highly favoured the crystallization of *dark pyroxene*, rich in calcium, magnesium, and iron, and relatively poor in aluminium. Agreeably to this supposition we find that, along the margins of the boss, especially in the west and north, there has been differentiated a basic magma of an almost pure pyroxenic composition, which has often crystallized as very coarse-grained *pyroxenite*, with as much as 95 per cent. pyroxene. An analysis from the laboratory of Herr L. Schmelck gave the following composition for such a very coarse-grained pyroxenite from Brandberget:—

Table VIII.

	Pyroxenite, Brandberget.	*Pyroxene, Limburg.*
SiO_2	45·05	44·65
TiO_2	2·65	2·93
Al_2O_3	6·50	6·62
Fe_2O_3	3·83	5·02
FeO	7·69	3·87
MgO	12·07	14·76
CaO	18·66	20·32
Na_2O	0·94	1·29
K_2O	0·78	0·49
$Ca_3P_2O_8$	0·31	......
H_2O	2·40	......
	100·88	99·95

For purposes of comparison the analysis by Merian (Neues Jahrb. 1885, Beilage, vol. iii. p. 285) of the pyroxene from Limburg, Kaiserstuhl, Baden, is placed beside that of the Brandberget rock. The agreement between the rock and the mineral is, as will be seen, very close.

The typical pyroxenite of Brandberget consists, practically in its entirety, of dark pyroxene; mingled with this, but quite subordinate, are a little brown hornblende, reddish-brown biotite, traces of plagioclase, etc.; the structure is often miarolitic, with various minerals (splendid crystals of titanite, apatite, etc.) in the open cavities.

This pyroxenite is traversed by innumerable, comparatively acid veins of fine-grained, light-grey augite-diorite, or mica-augite-diorite, invariably rich in yellow titanite, and of a kind passing into the series of augite-syenite, designated formerly by the author as 'akerites.' These veins of augite-diorite are so abundant that the rock on the whole of the western side of Brandberget represents a typical eruptive breccia, containing angular fragments of the dark coarse-grained pyroxenite cemented by the fine-grained, light-grey augite-diorite. This latter then represents the acid residuary magma after the differentiation of the pyroxenite-magma, already consolidated to pyroxenite, when its veins were squeezed up.

The main mass of the magma of Brandberget is not much differentiated, but has crystallized out like the basic olivine-gabbro-diabase mentioned above, differing only slightly from the above calculated average magma of olivine-gabbro-diabase.

All the products of crystallization on Brandberget represent, then, the results of a special differentiation, which has taken place in this boss itself. As we found above (p. 27) that 9 parts of the camptonite composition, and 2 parts of the bostonite composition, gave us the average composition of the olivine-gabbro-diabases of Gran and Modum, in a similar manner it should be possible by the mixture of some parts of pyroxenite, hornblendite, augite-diorite, and olivine-gabbro-diabase (of the analysed composition) to reconstruct an average magma very closely allied to the average composition of the olivine-gabbro-diabases of Gran, or perhaps slightly more basic. To establish this calculation I still need several analyses; a preliminary trial has shown the approximate proportions, and these proportions seem to agree with the observations made in the field as to the extension of the different kinds of rock on the hill-top. When, in a monograph on these basic rocks, I can present, as I hope to do, the exact calculation, founded on a sufficient number of analyses, showing that x parts of the analysed basic olivine-gabbro-diabase of Brandberget mixed with y parts of hornblendite, z parts of pyroxenite, and w parts of augite-diorite (all of analysed varieties from Brandberget) give about the average composition of the olivine-gabbro-diabase above calculated from the analyses of rocks from Brandberget, Sölvsberget, and Dignæs, then I hope to have proved that all the various kinds of rock from Brandberget must be considered as products of differentiation from a

magma only slightly different from the before-mentioned average-magma, which, for the sake of brevity, I will designate as magma O.[1]

If the average composition of the rocks of Brandberget is, possibly, a little more basic than the average composition of the bosses between Brandberget and Dignæs taken altogether—that is, is more basic than magma O—this is certainly not the case with the boss of Sölvsberget. The rocks of Sölvsberget on the whole undoubtedly possess an average composition conforming very closely to that of magma O. Besides, we have found that the bulk of the eruptive rocks on Sölvsberget is represented by an olivine-gabbro-diabase of nearly the average composition. Nevertheless I have also observed on Sölvsberget a series of differentiations of magma O, which are, on many accounts, of much interest.

Moreover, on Sölvsberget I have found the same pyroxenites as on Brandberget, although to a more limited extent, namely on the western and south-western side of the hill, as contact-facies; but I have not observed any hornblendite.

On the eastern end of the boomerang-shaped boss, where the tectonic relations have been quite exceptional, a peculiar differentiation has taken place. By this differentiation along the contact there is separated out a magma which has consolidated as labrador-porphyrite.

The chemical composition of this labrador-porphyrite has not yet been determined by analysis, but it is assuredly not very different from that of the labrador-porphyrite of Huken, north of Christiania, where this rock is spread as an old sunken lava-flow over large areas. An analysis of the Huken rock, made in the laboratory of Herr L. Schmelck, gave:

SiO_2	47·50
TiO_2	3·02
Al_2O_3	17·57
Fe_2O_3	7·24
FeO	5·08
MgO	3·31
CaO	6·19
Na_2O	3·60
K_2O	3·28
H_2O	1·70
$CaCO_3$	0·68
$Ca_3P_2O_8$	1·00
	100·17

The difference between this and magma O, as will be seen, is quite unimportant, because the composition for most compounds lies between magma O and the composition of the olivine-gabbro-diabase from Dignæs. However, a slight differentiation has taken place, the mixture of the labrador-porphyrite being poorer

[1] As above mentioned, the average composition of the rocks of Brandberget seems to be a little more basic than the average of the more southern occurrences.

in magnesia and lime, and richer in alumina and alkalies, than the chief rock of Sölvsberget (see p. 19). As is well known, the conditions of crystallization for pyroxene and labradorite overlap in certain magmas of gabbro and diabase-composition. We find, therefore, that in one case the plagioclase has crystallized essentially before the pyroxene (ophitic structure), in other cases the relation has been the reverse (as in several typical gabbros). A very slight alteration of the physical conditions (temperature and pressure) along the cooling margin on the eastern side of Sölvsberget must have been sufficient here to cause an increased diffusion of the plagioclase-forming compounds in the magma to take place towards the contact; while under the altered conditions the labradorite would have crystallized more easily than the pyroxene. The magma thus separated by a slight differentiation has then, on its subsequent consolidation, been cooled in such a manner that it has assumed a porphyritic structure, and consequently has left a labrador-porphyrite. This—in comparison with the main type on Sölvsberget—more acid rock is undoubtedly a later product of the magma, for we find, at Bjerget for instance, that the labrador-porphyrite is full of angular fragments of the common olivine-gabbro-diabase of Sölvsberget, developed as a characteristic eruptive breccia.

In the close vicinity of Sölvsberget there also occur dykes of augite-porphyrite, with the same mineral composition and structure as the lava-flows so abundant in the neighbourhood of Holmestrand, etc., which are the oldest effusive rocks of the Christiania region, and undoubtedly an outflow of the same magma as the basic rocks of Gran. These augite-porphyrites show only very slight, if any, difference in their chemical composition from magma O. The above-mentioned dykes are not then chemically differentiated in relation to the main rock-type of Sölvsberget: they merely represent good examples of the influence of differences in pressure and temperature, etc., on the products of crystallization. For the same magma, which by cooling slowly in the boss as an abyssal mass is consolidated to eugranitic olivine-gabbro-diabase, cooling more rapidly in dyke-fissures and on the surface as lava-beds, has left augite-porphyrites, quite different in structure and mineral composition. Examples of this kind are now well known from a multitude of localities; one need only call to mind the Monte Amiata in Tuscany, so well studied by the late F. R. Williams, whose premature decease we all mourn, and the magnificent monograph on the rocks of Electric Peak and Sepulchre Mountain published by J. P. Iddings. In the Christiania region examples of such relations are numerous.

The differentiations in the laccolite of the Viksfjeld show, in the main, similar relations to those just described; more acid quartziferous augite-diorites are here frequent as the latest products of differentiation. Time unfortunately does not allow of a detailed description.

VII. Conclusions.

In the preceding pages I have tried to set forth, in a brief *résumé*, a series of examples illustrating the fact that the compositions of eruptive rocks are sensible functions of the composition of the mother-magma, and of the manner in which this latter has been differentiated during cooling and diminution of pressure.

A magma of a composition closely allied to that above designated as magma O has, so far as I can at present form an opinion, been the oldest product of differentiation from the general magma-reservoir of the sunken tract defined by me as the Christiania region, this magma-reservoir itself having been, perhaps, a product of differentiation, in yet more remote ages, from a universal earth-magma. Magma O was then, if my deductions be correct, the source of all the different basic eruptive rocks in the Christiania region, especially also of the bosses, dykes, and sheets in Gran and the neighbouring parishes, and their equivalents, the effusive basic rocks of the series of augite- and labrador-porphyrites, etc.

In studying these rocks we have found examples of general relations of some importance :—

(1) That we can, with great certainty, connect a series of different dyke-rocks (camptonites and bostonites) with an exactly defined boss-rock of, *per se*, different mineralogical and chemical compositions.

Similar connexions are known from other regions. I need only call to mind the connexion of lamprophyric minettes with granites, often pointed out by our great master in general petrology, Prof. Rosenbusch, and recently so well described by Marr and Harker.[1] But in the present case I think that a connexion of this kind has been more definitely proved than in previously published instances.

(2) That the dyke-rocks in question—the camptonites and the bostonites—have probably been produced by differentiation in an abyssal magma of a certain chemical composition, which we have tried to calculate exactly from sufficient data. A calculation of this kind has not, so far as the writer is aware, been previously published.

(3) That the calculated basic mother-magma, or magma O, has partly consolidated in the bosses in Gran *without* being differentiated, as olivine-gabbro-diabases (type: Sölvsberget), and has partly been differentiated into camptonites and bostonites, but partly also into other kinds of rock: *i. e.* into pyroxenites, hornblendites, and more acid augite-diorites, etc. We have, then, here an example of the remarkable fact that *one and the same magma under different conditions has been differentiated in different ways*, and separated out so as to form different groups of rocks with different chemical compositions in the individual members of each group; we must above all remember that here is a question not only of different mineral-aggregates, but also of different chemical compositions.

It is thereby proved that the differentiation of a magma depends not only on the given chemical composition, but also essentially on

[1] Quart. Journ. Geol. Soc. vol. xlvii. (1891) p. 266; Geol. Mag. for 1892, p. 199.

the physical conditions under which the differentiation takes place. The '*kern*' hypothesis of Rosenbusch, in the form given by that author, does not fit in with these deductions.

(4) The observations here described probably further show the inverse case, that *the same group of differentiated rocks* (in the present case, camptonites and bostonites) *can be produced by separation from mother-magmas of quite different chemical composition.* In our case these dyke-rocks have been derived from an olivine-gabbro-diabase magma; in other instances we know that the same rocks are connected with nepheline-syenites (augite-syenites?), and have probably in those cases been differentiated out of a nepheline-syenitic (augite-syenitic?) magma. This being so, we have another fact which does not agree with the '*kern*' hypothesis.

(5) I have endeavoured to prove that the inferred *differentiation has been determined by, and is dependent on, the laws of crystallization in a magma* in so far as the compounds, which on given conditions would first crystallize out of the magma, must have diffused to the cooling margin, and in this way have produced, in the contact-stratum, a peculiar chemical composition in the still liquid magma before any crystallization took place.

By the pressing-up in this manner of the differentiated masses to a higher level at lower temperature and pressure, or by continued cooling along the contact-margin with subsequent crystallization, there have then been produced different kinds of rock of peculiar chemical composition, mineralogical constitution, and structure. The sequence of eruptions from a common magma-basin (magma-reservoir) must therefore, to a certain extent, be parallel with the sequence of crystallization in the corresponding kinds of rock. Many years ago, I tried to prove that this opinion is really confirmed by my observations on the rock-succession in the Christiania region, which closely conforms to the sequence of crystallization in the corresponding abyssal rocks in this 'eruptive province.' A series of confirmatory examples is known from the literature of other countries, from the British Islands by the excellent publications of Sir Archibald Geikie, Messrs. Teall, Dakyns, and other authors. The examples are really so numerous that they seem to represent a general law. No doubt in many cases the rock-sequence in different 'eruptive tracts' does not appear to agree with this empirically deduced law. But that does not prove that the law has no existence; it only shows that other conditions besides those above-mentioned are of importance for the determination of the eruptive sequence. A discussion of the great number of different possible cases (for instance, the hypothesis of Iddings as to the eruptive sequence, etc.) would on this occasion lead us too far. Here my intention has been simply to present a series of observations from a single locality, in which the genetic relations between the different kinds of rock seem distinctly to favour the opinion of a conformity between the sequence of crystallization and that of differentiation.

So far, I think, we are on safe ground; I would expressly point out that I have not discussed the primary reason for a differentiation of the above-described nature, whether this is to be sought for in Soret's principle, in the effect of chemical affinity, or in other causes. That in many cases also the principle of Guy and Chaperon, the commencement of crystallization and the sinking to the bottom of the crystallized masses, as well as a subsequent re-melting of such early crystallizations, may have performed a part in the processes of magma-differentiation is quite possible. We move here in a maze of hypotheses.

But the differentiation itself is not a hypothesis; it must now be reckoned with as a solid fact of great importance. The same law, which in a narrow dyke-fissure has produced a differentiation along the more rapidly cooling dyke-sides, has, operating on a larger scale in the magma-basins in the earth's crust from which eruptions of a local volcanic centre originate, differentiated out the pressed-up secondary magmas, so that they have succeeded each other in a regular order. Finally, the same law has perhaps determined the particular composition of the magma of each separate magma-basin by differentiating the same out of the *pristine* liquid magma upon which, by the cooling of the earth, the solid crust was deposited.

Discussion.

The President said it was of advantage to the Society to have communications of this kind from distinguished foreign geologists. The paper reminded him of one by Dakyns and Teall, published in Quart. Journ. vol. xlviii. (1892). The basis of this philosophy appeared to lie in the determination of the order of crystallization by the microscope. The theory must be supported by very clear field-evidence, otherwise it would remain a mere speculation.

Prof. Judd said that the Geological Society of London must hail with pleasure the fact that Prof. Brögger had chosen their Journal as the means of communication to the world of a memoir of such value and interest. Prof. Brögger's contributions to all branches of geological and mineralogical science are so large in amount and invaluable in character that his claims on the attention of geologists are unrivalled. The speaker especially referred to the novelty and interest of the Author's views concerning the mode of separation of magmas, and to his suggestion that the nature of contact-metamorphism depends on the character of the erupted rock, as well as on the materials through which it has been ejected.

Gen. McMahon remarked that the Author appeared to hold the view that the differentiation of a magma into a continuous series of rocks, ranging from those of a more basic to those of a more acid type, depended on the laws that determine the sequence of crystal-building—that is to say, that the more basic minerals are those which first crystallize out from a magma, the remaining minerals

following in the order of their basicity. Further, the Author held that the more basic rocks were older—that is to say, were erupted before the more acid ones; the latter, as Mr. Teall explained, forming dykes cutting the more basic rocks. If this were so, it would follow that, as the differentiation in the general magma progressed, the basic material would sink to the bottom and the acid portion of the magma would remain at the top. When pressure was exercised on a fluid, or viscid, magma differentiated into layers in the way supposed, and eruptions began to take place, one would have expected the acid top layer to have been the first to have issued from the cauldron. It was a pity that the Author was not present, as he (the speaker) would very much like to learn by what physical process the deeper-seated and more basic portions of the still fluid magma were first erupted.

Prof. J. F. Blake and Mr. W. W. Watts also spoke.

4. *On a* PICRITE *and* OTHER ASSOCIATED ROCKS *at* BARNTON, *near* EDINBURGH. By HORACE W. MONCKTON, Esq., F.L.S., F.G.S. (Read December 6th, 1893.)

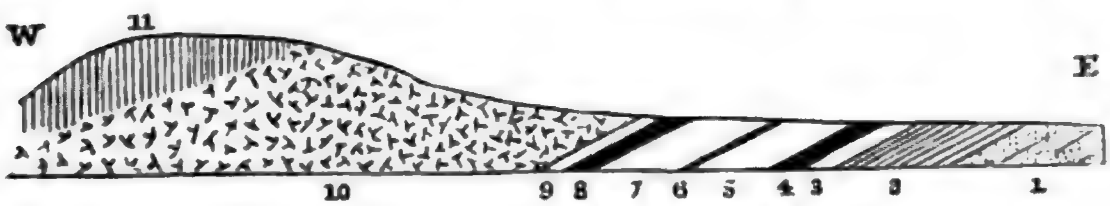
THE Barnton Branch of the Caledonian Railway leaves that Company's Edinburgh and Leith line immediately north of Craigleith Station, opposite to Sir James Maitland's great Craigleith Quarry. The Barnton line lies almost entirely on Sir James's property, and I have to thank him for assistance in collecting the facts I now record. On our last visit to the locality we first inspected a trial pit, east of the old railway and close to it, a little north of Craigleith Quarry. The section was as follows:—

1. Surface-bed, with a few large boulders.
2. Thinly-bedded sandstone, about 12 feet.
3. Shaly beds, with an easterly dip of 1 in 4.

The first cutting on the new line is about ¼ mile from the junction at Craigleith. It is 19 feet deep and entirely in Boulder Clay. At from 3 to 4 feet below the top of the cutting there is a remarkably even line of very large boulders, and in one place I noted below them a patch of yellow sand 2 feet thick. The rest of the sides of the cutting is formed of black clay, full of small stones.

More Boulder Clay is shown between House o' Hill and Drylaw, but it is not till we reach Barnton Park that we find a section showing the solid geology. In the first cutting in the park the beds of the Calciferous Sandstone Series are seen dipping westward at an angle of about 30°, and as I began my examination at the eastern end they are here described in ascending order.

Diagram-Section on the Barnton Railway in Barnton Park.



11. Dolerite.
10. Picrite, through which run veins of basalt.
9. Indurated shale.
8. Igneous rock.
7. Indurated shale or 'calm.'
6. Igneous rock, 1 foot (mica-porphyrite).
5. Indurated shale.
4. Igneous rock, 12 feet (mica-porphyrite).
3. Indurated shale.
2. Black shale, with veins of calcite,
1. Thinly-bedded sandstone.

Much of the shale of beds 3, 5, and 7 is of a whitish colour and very hard, of the kind locally termed 'camstone' or 'calm.' A similar rock is, I believe, quarried in Corstorphine Hill.

Associated with this shale are some beds of igneous rock. Microsections have been made from bed No. 4 and from bed No. 6.

They are very similar one to another. There are a few porphyritic crystals of a green mineral which may to some extent replace olivine; but I think that in most cases it more probably replaces augite. The shape of the crystals is not quite that of olivine, and in the slide from bed No. 4 there are one or two crystals not so much altered as the rest, and one of them seems to extinguish at an angle of about 45°, and is, I think, certainly augite. Perhaps some of these green crystals, especially some of those in the slide from bed No. 6, may be alteration-products after bastite. Some of them are bordered with small flakes of brown mica (no doubt secondary), and there is a great deal of brown mica in the groundmass, the flakes of which are minute in bed No. 6, while in bed No. 4 they are often 0·006 inch long. There are some small crystals of augite, and a great deal of very much altered plagioclase-felspar in small lath-shaped crystals. Many zeolites occur all over the section, and there are a few crystals which I think may be epidote.

At one spot in the micro-section from bed No. 6 there is a very pretty group of zeolites at the base of the igneous rock, where it rested on the shale of bed No. 5. It is not very easy to name this rock. Perhaps 'mica-porphyrite' is the most appropriate appellation, although the rock can scarcely be said to contain porphyritic felspar: it is somewhat nearly allied to kersantite. The mica-porphyrite lies very evenly between the beds of stratified rocks, but the great induration of the shales above and below it shows that it is probably intrusive.

[When I sent this paper to the Society I was not aware that the cutting had already been described by Mr. John Henderson and Mr. J. G. Goodchild.[1] The former of these authors mentions the igneous rock which I have called mica-porphyrite as 'intrusive greenstone.' The picrite and overlying basalt he describes as a mass of greenstone dipping conformably with the shales, and having an apparent bedding and dip to the west. This apparent bedding, due to planes of jointing, is very marked. Mr. Goodchild points out that a portion of this mass of greenstone is picrite: he does not deal with the mica-porphyrite.]

The picrite is No. 10 of the section (see p. 39), and it forms the sides of the cutting for some distance. The greater portion is soft and granular, but hard parts may be found here and there. The planes of jointing are fairly parallel to the stratification of the shales, etc., which underlie it.

Under the microscope it is seen to be composed of:—

(1) *Serpentinized olivine*, in more or less rounded grains of very different diameters—one of medium size measures 0·08 × 0·04 inch. The olivine has been altered into a mineral of a brilliant yellow colour, with a somewhat parallel fibrous structure, and round the edges of the grains a further alteration into a bluish-green and more markedly fibrous mineral has taken place. This mineral is dichroic, changing from bluish-green to yellow. Sometimes, especially

[1] Trans. Geol. Soc. Edinb. vol. vi. part v. (1893) pp. 297, 301.

among the smaller grains, the whole or nearly the whole grain has been changed into the green mineral. The extinction-angle of these minerals may be a little oblique, but of that I am not quite sure. In any case there can be no doubt that they are alteration-products of olivine. Most of the grains contain scattered specks of iron oxide.

(2) *Augite* of a light pink colour, in grains of most irregular shapes, fairly well preserved and sometimes more than $\frac{1}{10}$ inch in length. The larger grains contain enclosures of the altered olivine, microliths, etc.

(3) *Felspar.* A very few lath-shaped crystals; the largest measures $0{\cdot}04 \times 0{\cdot}0075$ inch.

(4) *Mica* in flakes, of which one of an average size measures $0{\cdot}015 \times 0{\cdot}01$ inch. They are orange and yellow-brown in colour, and are dichroic.

(5) *Iron Oxide,* in grains and granules down to fine dust, scattered through the altered olivine. It does not occur in the augite, except in connexion with altered olivine-enclosures.

There is in places much interstitial matter of a turbid white appearance, which may be, at least in part, altered felspar.

In pl. xxvii. of the 'Minéralogie Micrographique' of MM. Fouqué and Michel-Lévy a micro-section is figured of a rock in which alteration has taken place, somewhat like the alteration of the olivine in the Barnton picrite. The crystals in the French rock are, however, more regular and clearly defined than the crystals of altered olivine in the Barnton rock—which are not unlike the serpentinous pseudomorphs after olivine in the micro-section of the Menheniot picrite figured by Mr. Teall.[1]

In one illustration of the Inchcolm picrite by the same author[2] a crystal is shown, surrounded by small flakes of hornblende, which is not unlike the green crystals in bed No. 6 of the section here described, in which, however, the peripheral mineral is brown mica. It will be remembered that the island of Inchcolm lies in the Firth of Forth, $4\frac{1}{2}$ miles north of the Barnton railway-cutting.

I submitted a micro-section from the Barnton picrite to Prof. Bonney, F.R.S., and he has very kindly furnished me with the following remarks on its affinities with other picrites:—"The change of the olivine here exhibited is not the one so usually seen. It is more regular, more uniform, and more analogous to the change of the enstatite-group. We have it in the Porthlisky picrite, the Menheniot picrite (but here are some other peculiarities in the network of microliths), traces of a similar structure in the Duporth rock (here, however, I suspect an altered bastite), also in a picrite boulder from near Liskeard (possibly connected originally with Menheniot). I have, however, seen it in some true serpentines.

"The Barnton rock comes in many respects very near to the

[1] 'Brit. Petrogr.,' 1888, pl. ii. fig. 2.
[2] *Ibid.* pl. vii. fig. 1.

picrite of Inchcolm, but the latter rock is less altered.[1] I have, however, in my collection specimens which show more complete change and so approximate more closely. After looking through a considerable number of specimens of picrite in my collection I have no hesitation in saying (1) that the Barnton rock is a genuine picrite; (2) that it is most probably an offshoot from the same magma as that which supplied the Inchcolm rock. It differs from the Bathgate rock."[2]

Through the bed of picrite run veins of a very different character. The vein-rock is holocrystalline and consists of:—

(1) *Augite*, well preserved, white, brown, and pinkish in colour, in large crystals.
(2) *Plagioclase-felspar*, in large crystals showing twin-striation. Originally the plagioclase formed a large proportion of the rock, but it is now to a great extent changed into a turbid white mineral.
(3) A greenish-yellow, secondary mineral, which has scarcely the shape of olivine—it may be bastite, but is not unlike the green mineral found in beds Nos. 4 and 6 (mica-porphyrite), and possibly it may be a peculiar variety of augite.
(4) There are several brown and greenish dichroic crystals. Some of these are apparently mica, some are hornblende. About others I feel considerable doubt—possibly they may be an actinolite.
(5) *Iron oxide* is fairly abundant.
(6) *Zeolites* occur, as in the rock of bed No. 6.

Mr. John Henderson described one of these veins, probably the same as that from which I brought away a specimen, as a vein or thin dyke cutting the 'trap' and passing obliquely from below to the surface.[3] Mr. Goodchild considers them to be segregation-veins. Perhaps they may be described as dolerite, more especially as they bear a strong resemblance to the igneous rocks of No. 11, which overlies the picrite and is certainly an ophitic dolerite.

A reference to the Geological Survey Map (Sheet 32, Scotland) will show that the Corstorphine Hill mass of igneous rock projects northward towards the Forth, and the cutting which I am describing is situated nearly at the northernmost end of the patch mapped. Accounts of the igneous rock of Corstorphine Hill are given by Mr. Allport and Mr. Teall,[4] and their descriptions agree well with a micro-section cut from a specimen which I obtained in Sir James Maitland's large quarry, south of the Queensferry Road,

[1] See A. Geikie, Trans. Roy. Soc. Edinb. vol. xxix. (1879) p. 507; also Teall, *op. supra cit.*
[2] A. Geikie, *op. supra cit.*
[3] Trans. Geol. Soc. Edinb. vol. vi. part v. (1893) p. 299.
[4] Quart. Journ. Geol. Soc. vol. xxx. (1874) pp. 557–558; 'Brit. Petrogr.,' 1888, p. 190.

and about 2½ furlongs from the 'picrite'-cutting on the Barnton Railway.

My Corstorphine Hill specimen resembles to a certain extent the specimen from the vein running through the picrite which has just been described. In both cases there are augite-crystals particularly well preserved, and in both the felspar is largely replaced by some other mineral; but whereas in my railway-cutting micro-section some felspar-crystals are seen showing twin-striation very clearly, there is not one in the Corstorphine Hill micro-section—so complete is the alteration of the felspar in that rock. Mr. Allport, however, mentions that in micro-sections from some parts of Corstorphine Hill a little plagioclase is preserved. The brown dichroic mineral of the rock from the railway-cutting seems absent from the Corstorphine Hill specimen. I am not certain as to pseudomorphs after olivine in the railway-cutting specimen, but they undoubtedly occur at Corstorphine Hill; and there are some pale-green aggregates of a fibrous or radial structure, forming plates into which the felspar-crystals penetrate as in an ophitic dolerite. Probably they represent a pyroxene, now replaced by actinolite and serpentine.

The remaining cuttings on the Barnton Railway showed Boulder Clay, the boulders being few, but large.

In conclusion, I must express my indebtedness to Prof. Bonney for kindly looking at the micro-sections and for assistance generally. He allows me to say that he agrees with the determination of the minerals mentioned in this paper.

Discussion.

Sir James Maitland said that he had on several occasions visited the section described, and had seen the paper from which some extracts had just been read. The 'calm' or indurated shale in connexion with the intrusive igneous rocks at Barnton was very like that which occurred to a depth of 36 feet in a similar relation to the basalts of Sauchie (Stirling). Other things of interest were found in the Barnton cutting: for instance, a heap of recent sea-shells was cut through about the 170-feet level, the same level as that of the large boulders resting on patches of sand described in the paper; and a short distance west of Barnton he had found good oil-shale forming practically the top of the solid geology, and covered with over 100 feet of alluvium. The six-inch map hung on the screen was an old one, and did not show an intrusive sheet of basalt to the east and north of Craigleith, which separates that famous quarry from an excellent bed of building-stone proved during the last month to a depth of 45 feet.

5. *The* Purbeck Beds *of the* Vale *of* Wardour. By the Rev. W. R. Andrews, M.A., F.G.S., and A. J. Jukes-Browne, Esq., B.A., F.G.S. (Read December 6th, 1893.)

Contents.

I. Introduction.

Although the Purbeck Beds of the Vale of Wardour have been noticed by many observers, and portions of them have been described by many writers from the time of Fitton downwards, no complete description of the whole series has yet been attempted, and a connected account of the Wiltshire Purbecks seems therefore to be a desideratum in geological literature.

Fitton gave some account of them in his classical memoir 'On the Strata between the Chalk and the Oxford Oolite,' published in 1836,[1] mentioning quarries at Dallard's Farm, Dashlet, Chicksgrove Mill, and Wockley; but since his time the Wockley quarry has been cut back, so as to expose the beds which were then only visible at Chicksgrove. He made no attempt to establish any succession, and thought the total thickness of the series was not more than 60 feet.

The Rev. P. B. Brodie, in 1845, published a little book entitled 'A History of the Fossil Insects in the Secondary Rocks of England,' in which he gave some description of the Purbeck Beds of the Vale of Wardour, and especially of two beds of limestone, one of which he called the 'Isopod Limestone,' because it contained *Archæoniscus*, and the other the 'Insect Limestone,' from the abundance of insect-remains in it. Unfortunately, his reference to localities was not very explicit, but it is certain that the quarries "not far from the village of Dinton," where he saw these limestones, are not now open, and the details he gave were so different from the Dallard's Farm section described by Fitton that they could not possibly represent the same beds.

In 1850 Edward Forbes read a paper at the meeting of the British Association at Edinburgh on the Purbeck series of Dorset,[2] which he proposed to divide into Lower, Middle, and Upper groups, according to the prevalence of certain species of Cyprids. This paper

[1] Trans. Geol. Soc. ser. 2, vol. iv. pp. 103–388*.
[2] Subsequently published in Edinb. New Phil. Journ. vol. xlix. pp. 391–394.

induced Mr. Brodie to revisit the Vale of Wardour, and in 1854[1] he published a short account (but more connected than his previous one) of the Wiltshire Purbecks. He stated that the Upper division is wanting, but that the Middle and Lower groups are tolerably well-developed; he gave a descending section drawn up by the Rev. O. Fisher, in which the demarcation between Middle and Lower Purbeck was fixed at a certain dark clay overlying a limestone which contains *Cypris purbeckensis*. Mr. Fisher also for the first time recognized the 'Cinder-bed' in the Vale of Wardour; but the Wockley section was not mentioned, and no attempt was made to estimate the total thickness of the Wiltshire Purbecks.

The district was mapped by the Geological Survey during the years 1852, '53, and '54, the map (sheet 15) being issued in 1856; but no explanatory memoir has ever been published, nor did the surveyor ever publish any account of his observations.

A detailed account of the Middle Purbeck Beds exposed in the railway-cutting south of Teffont was written by one of us in 1881, to accompany Mr. Etheridge's description of a new species of *Trigonia* from the 'Cinder-bed' of that locality.[2] The four lowest beds of that section were grouped as Lower Purbeck, but it was subsequently found that they really belonged to the Middle Purbeck, the base of that division not being exposed in the cutting.

A general account of the geology of the Vale of Wardour was compiled by the same writer, and printed in the Proceedings of the Dorset Nat. Hist. & Antiq. Field Club for 1883, vol. v. pp. 57–68.

In 1890, while one of us was engaged in examining the Cretaceous rocks of Wiltshire, we jointly surveyed the eastern end of the Vale of Wardour, with the special object of separating the Purbeck from the Wealden, and of ascertaining whether any Vectian Sand intervened between the latter and the Gault. The work was done on the six-inch Ordnance maps, and the result of our survey was to convince us that not only were all these formations present, but that a considerable thickness of strata lay between the recognized Middle Purbeck and the beds regarded as Wealden. These strata seemed to be so clearly an upward continuation of the Purbeck series that we felt justified in referring the greater part of them to the Upper Purbeck group, a division which had not previously been recognized in the district. The existence of these Upper Purbeck Beds was announced in the Geol. Mag. for 1891, p. 292, and in that note we expressed our intention of preparing a more detailed account of the Purbeck series. The present communication is the fulfilment of that intention.

The correlation of the beds exposed in the various quarries and cuttings in the central part of the Vale is by no means an easy task, for though easterly dips are prevalent, and higher beds come in gradually towards the east, yet this general inclination is so

[1] Quart. Journ. Geol. Soc. vol. x. p. 475.
[2] *Ibid.* vol. xxxvii. p. 246.

interrupted by cross-rolls, and apparently also by small faults, that the relative position of a section is no guide to its real geological position. The consequence is that, unless some particular bed can be identified with one seen elsewhere, it is very difficult to refer an isolated exposure to its proper place in the series. There are a few such sections about the position of which we are still uncertain, but we think the beds seen in them will prove to be only the equivalents of some of the strata described in this paper.

We are indebted to Prof. T. Rupert Jones, F.R.S., and Mr. C. Davies Sherborn for identifying the Cyprids which we collected, and to Messrs. G. Sharman and E. T. Newton, F.R.S., for naming some of the mollusca.

II. General Structure of the District.

The main features of the geological structure of the Vale of Wardour are well known. It will suffice to say that the Purbeck Beds come in at the eastern end of the Vale, because an easterly dip was imparted to the Jurassic system before the superposition of the Cretaceous strata upon it. The uncovering of the Purbeck Beds at this locality is due to the denudation which has taken place along the axis of a post-Cretaceous anticlinal flexure.

The axis of this anticlinal does not, however, coincide with the lowest or central part of the valley, but runs nearly due east-and-west through Lady Down and Teffont Evias, its northern limb being much shorter and more steeply inclined than its southern limb. Moreover, the pre-Cretaceous dip of the Jurassic strata was not due east, but nearly south-east; neither was this south-easterly dip a steady and continuous one, but interrupted by cross-rolls and faults, so that the present disposition of the outcrops results from the interference of three distinct sets of disturbances. The consequence of this interference is to produce a number of divergent dips, and to make the mapping of the subdivisions of the Purbeck series rather complicated.

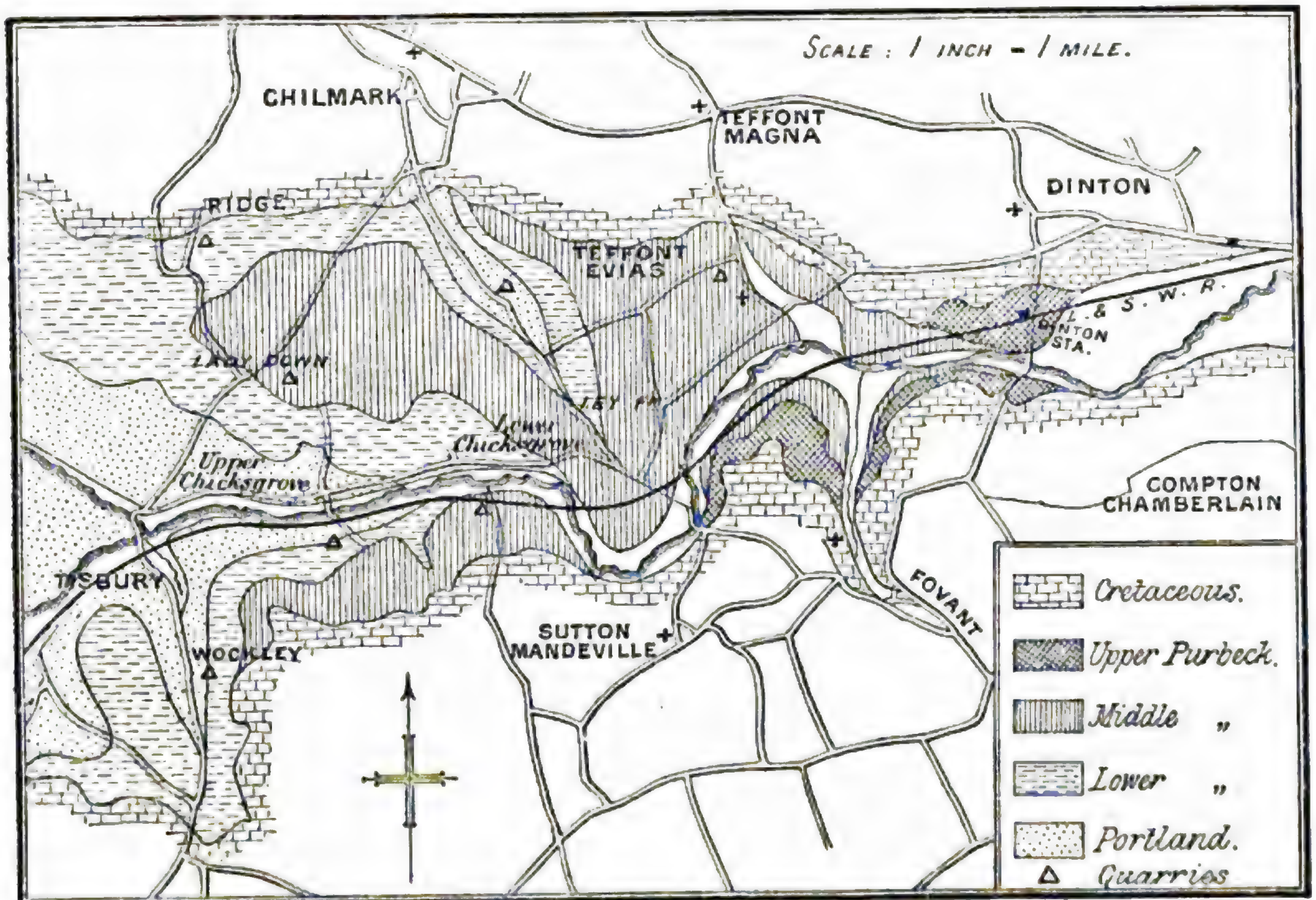
Although the beds are horizontal on the top of Lady Down, they slope thence rapidly south-eastward, and the base-line of the Middle Purbeck group falls through 200 feet in less than two miles, owing to the combined effect of the original dip and the inclination of the southern limb of the post-Cretaceous anticlinal.

The axes of the pre-Cretaceous flexures strike from north-west to south-east, and going from west to east the following flexures may be noticed:—

(1) The anticlinal of the Chilmark Valley, which brings up the Portland Beds near Chilmark, but seems to die away southward, or is masked by the steep south-easterly inclination of the axis.

(2) A synclinal bringing in what seems to be the base of the Upper Purbeck group in a small cutting on the railway near Daslett Farm.

Geological Sketch-map of the Vale of Wardour.



Note.—The crosses indicate the position of the village churches.

(3) An anticlinal corresponding with the Teffont Valley, and bringing up the Lower Purbeck Beds into the cutting near Teffont Mill, where they are much disturbed and even contorted.

(4) A synclinal, with probably a fault, between the first and second cuttings on the line west of Dinton Station.

(5) An anticlinal seen in the first cutting west of Dinton Station.

The sketch-map on p. 47 is reduced from the six-inch maps on which we recorded our observations, and we have ventured to draw a complete boundary-line between the Lower and Middle Purbeck Beds, although it should be stated that we did not trace this over the ground, but drew it in afterwards from a consideration of the data collected: these are, however, sufficiently numerous to prevent any serious error.

The complete discordance between the Purbeck Beds and the Lower Cretaceous series, including the Wealden, is clearly shown by the manner in which the base of the latter passes across the anticlinal of the Chilmark Valley without being affected thereby.

III. The Lower Purbeck Group.

There are two localities in the Vale where the junction of the Portland and Purbeck strata can be examined, namely Chilmark and Wockley; but, although the two quarries are only two miles apart, the beds seen in the one are so different from those seen in the other that it is hardly possible to compare the two sections.

It will be convenient to begin with the Chilmark section as being, in some respects, the simplest. This is shown in the higher quarry on the eastern side of the Chilmark Valley, and is as follows:—

		Feet.	Inches.
Lower Purbeck.	Shaly marl, with lenticular beds of soft limestone, bedding wavy	2	0
	Yellowish tufaceous limestone	0	8
	Soft, white, chalky limestone ... about	1	0
	Stiff grey clay, containing pebbles of whitish limestone and many pieces of wood; base uneven: from 1 foot to	1	8
	Tufaceous marly limestone, very soft in places and irregularly bedded: ... varies from 5 feet to	6	6
	Yellowish oolite, with lenticular layers of brown oolitic flint at the top	1	3
	Course of clear brown, glassy flint	0	3
	Hard, compact, tufaceous limestone	4	0
	Soft, dark grey, marly clay; purplish in places	0	3
Portland.	Firm yellowish oolite in thick beds, the upper surface rather uneven ... seen for	16	0
	White chalk, with flints, in quarry below	24	0

In this section there is no decided break or strong line of division between the Portland and Purbeck Beds. The oolite with the curious oolitic flint is very like that which is classed as Portlandian: but it seems reasonable to regard the tufaceous limestones as belonging to Purbeck rather than to Portland time, and as they contain only a few small bivalves resembling *Cyrenæ* we have so classed them, taking the dark clay-band as the basement-bed of the Purbeck series.

The grey clay which rests on the upper tufaceous limestone is a remarkable bed, and appears to be the relic of an actual terrestrial

surface. An upright and rooted stump of a tree (exogenous) was found in it, the stem standing about 6 feet high, and a portion of this is still preserved at the quarries; a specimen of *Cycadeoides microphylla* was picked up on the talus just below, and doubtless came from this bed. Fragments of wood are common in it.

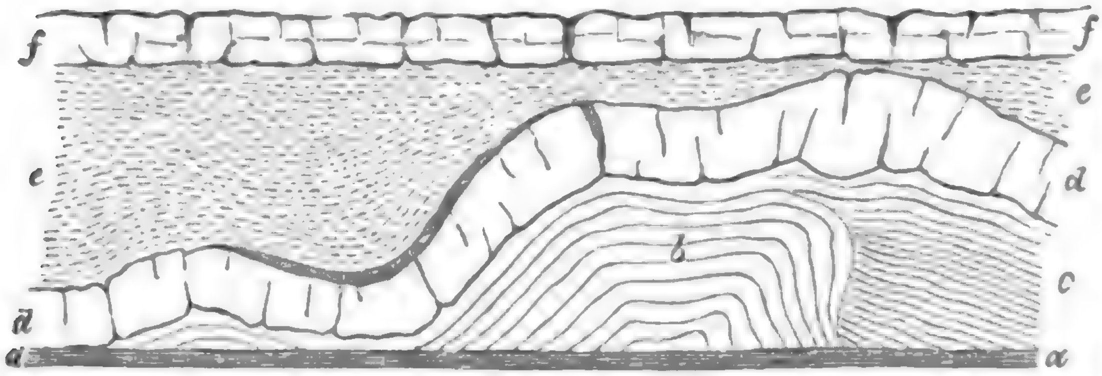
We find that Prof. J. F. Blake has given a section of this quarry which differs little from the above, but he remarks that the section does not agree with Fitton's account. We cannot find, however, that Fitton gave any account of this section, which was probably not exposed at the time he wrote, for he only observes that "among the loose matter at the top of these quarries is botryoidal carbonate of lime, passing into compact freshwater limestone, like the 'Cap' of Portland." (Trans. Geol. Soc. ser. 2, vol. iv. 1836, p. 255.)

We think that Prof. Blake must have made some confusion between Chilmark and Chicksgrove, for he mentions both places in connexion with the same section. It was Chicksgrove Mill quarry which Fitton described in detail, and the slab of stone referred to by Prof. Blake which is preserved at the Museum of Practical Geology in Jermyn Street, and is supposed to show the junction of marine Portland with freshwater Purbeck, must also have come either from Chicksgrove or Wockley. The succession at these two localities is substantially the same, but is very different from that of Chilmark. The Chicksgrove section is now obscured and weathered; the quarry at Wockley, however, is still worked, and the following succession of beds was there displayed in 1890:—

		Feet.	Inches.
Lower Purbeck. 22 feet 3 inches.	Hard, flaggy, oolitic limestone, with Cyprids	1	6
	Soft marly stone passing down into argillaceous marl	1	6
	Sandy brown clay	0	3
	Grey oolitic stone with Cyprids	0	4
	Laminated, grey, sandy marl passing down into soft, yellow, sandy marl; Cyprids	1	8
	Layer of brown clay	0	2
	Hard tufaceous limestone	1	0
	Soft, white, silty marl, interlaminated in the upper part with layers of brown sandy clay	1	9
	Parting of black and brown clay	0	1
	Rather hard, whitish, laminated marl	1	2
	Dark-grey, sandy and earthy clay	0	9
	Buff-coloured, laminated, marly limestone	2	6
	Black laminated clay, including a layer of grey limestone from 1 to	1	6
	Yellow ferruginous stone	1	0
	Soft, yellowish, sandy marl, overlying an undulating bed of grey marly limestone, beneath which is disturbed tough grey marl	5	0
	Laminated brown and grey clay, with patches of black clay: rests on the uneven surface of the bed next below	0	4
	Hard, whitish, chalky limestone with Cyprids, and a layer of cherty stone with small lenticules of flint at the top	1	3
	Soft, grey and white, laminated marl	0	6
Portland.	Hard flaggy limestone with black flints at the top, passing down into chalky and shelly limestone	2	3
	Chalky limestone, with Portland fossils	14	0

Fig. 1 shows the curious arrangement of the beds which overlie the thin layer of grey, brown, and black clay near the base of the Purbeck series.

Fig. 1.—*Beds seen in Wockley Quarry.*



a. Laminated Clay. *b.* Grey Marl. *c.* Hard Fissile Marl. *d.* Marly Limestone. *e.* Yellowish Sandy Marl. *f.* Yellow Ferruginous Stone.

West of the spot where this sketch was taken, the yellow sandy marl descends and cuts out the grey limestone and marls, but contains patches of grey marl and pebbles of the grey limestone; while at the eastern end of the quarry the yellow sandy marl is absent, its place being taken by a loose grey marl resting on an irregular surface of hard, light-grey, flaggy limestone, the top of the marl being hard and passing in places into a grey limestone; these beds are between 6 and 7 feet thick.

It is evident that much contemporaneous erosion took place during the formation of this part of the series, and the details of it vary in every ten yards. It appears to correspond with the 'Broken Beds' of the Dorset Purbecks. The grey beds seem to have been deposited first, and to have been subsequently exposed to the action of a strong current which disturbed them and in places completely destroyed them, embedding the broken remnants of them in the yellow sandy marl which was deposited as the strength of the current diminished. The surface being thus levelled up again, an even floor was formed, upon which the material of the yellow ferruginous stone was quietly accumulated.

On comparing the Wockley section with that of Chilmark Quarry, it will be seen that neither the thick oolitic freestone of the Chilmark Portlandian nor the tufaceous Lower Purbeck limestones are present at Wockley. There is certainly nothing which can possibly represent the freestone, and the Lower Purbeck of Wockley is so different from that of Chilmark that no one particular bed can be recognized at both localities. If, however, the grey clay (with limestone-pebbles) of the Chilmark section be on the same horizon as the confused grey marls of Wockley, there would seem to be a thickness of about 30 feet at the former locality, which is represented by only about 2 feet at the latter.

Under such circumstances it might be expected that the plane of division between the Portland and Purbeck series would be clearly marked, if not accompanied by signs of erosion; but this is not the case, and it is on the contrary difficult to decide where the divisional plane should be taken. The flaggy and shelly portions of the 2 ft. 3 in. bed are firmly welded together, and would yield a slab like that at the Museum of Practical Geology, in which Portland shells are visible in the lower and Cyprids in the upper part, but these Cyprids are not freshwater species, being in fact *Candona ansata* and *C. bononiensis* (which are estuarine forms). From the flaggy portion two species of fish have been obtained (*Ophiopsis breviceps* and *O. penicillatus*) and also a large species of *Archæoniscus*; but none of these fossils afford very good evidence for classing the flaggy bed as Purbeck; even the *Archæoniscus* doubtless existed on the land-surfaces of Portland times, and might therefore be washed into the shallowing bay or estuary.

The overlying marl contains Cyprids, but they are not recognizable; from the chalky limestone we obtained better specimens, which Prof. T. Rupert Jones identified as *Candona ansata*, and a form like *Cypridea punctata*, while in its highest cherty layer occurs what appears to be *Cypris purbeckensis* associated with a *Cardium* and *Corbula alata*.

Thus both strata and included fossils show a gradual passage from Portland to Purbeck conditions; but, as the line must be drawn somewhere, we prefer to take it at the base of the laminated marl, and consequently to relegate the flaggy stone to the Portland series.

To account for the great difference between the Wockley and the Chilmark sections, we can only suppose that Wockley lay in the track of a tidal current which prevented rapid deposition and subsequently caused the erosion of the grey beds; while the Chilmark area was either a low-lying sandbank or a backwater out of the track of the main current, and close to the influx of springs or streams which contained a large amount of carbonate of lime in solution, the carbonate of lime being deposited partly as oolite while the lagoon was still open to the sea, and partly as tufa after this opening had been closed.

If the white marl be taken as the basement-bed, the thickness of Lower Purbeck exposed at Wockley is about 22 feet (see p. 49). The Cyprids observed in the oolitic stone at the top of the quarry proved to be *Cypris purbeckensis*.

Near the hamlet of Ridge, 1¾ mile north of Wockley, and about 1 mile west of the Chilmark section, is a quarry exposing beds which we believe to be in the higher part of the Lower Purbeck series, the floor of the quarry probably lying not far above the horizon of the topmost bed in the Wockley section. The succession observed at Ridge in 1890 was as follows:—

		Feet.	Inches.
	Dark brown soil	1	0
12.	Weathered marlstone or 'lias'	1	0
11.	Buff-coloured marl, with two seams of grey clay	0	6
10.	Soft, fine-grained, marly oolite, with thin layers of harder compact marlstone in the lower part	2	3
9.	Soft, yellowish, calcareous oolitic sand	0	9
8.	Very hard limestone, consisting of shelly layers alternating with seams of compact marlstone	0	10
7.	Soft marl in thin layers	0	8
6.	Soft, yellowish, oolitic stone, with thin layers of marl	2	6
5.	Hard grey limestone, full of shells	2	4
4.	Firm oolitic stone, almost a pisolite in places, with interlaminated layers of marl in the lower part and a 2-inch layer of brown marly clay at the base	3	3
3.	Soft calcareous stone, passing down into hard limestone with vertical joints, and lying in thick courses	3	3
2.	Soft, grey, laminated, argillaceous marl	1	0
1.	Firm buff-coloured marlstone, breaking with semiconchoidal fracture; base not seen	3	0
		22	4

Limestone No. 3 is of estuarine origin, for the central part is full of marine shells, *Corbula alata*, with small species of *Perna*, *Cardium*, and *Leda*, *Serpula*, and small Univalves. There are also many angular hollows left by the solution of salt-crystals; the walls are so crushed in, that some of them look like four-rayed stars; some are empty, others are filled with a yellowish ferruginous earth.

Nos. 6 and 9 are curious oolitic sandstones; when treated with dilute hydrochloric acid the mass of the rock disappears, but if the residue is washed and evaporated a very small quantity of fine sand remains, consisting of minute grains of clear translucent quartz. Such granules probably form the nuclei of some of the oolitic grains, but most of these must be purely calcareous.

The higher bed No. 10 is only partially oolitic, and appears to be a mixture of oolitic particles with triturated shells of *Cyclas*, Cyprids, etc.; but no specifically recognizable Cyprids were observed.

The dip of the beds at this quarry is about 4° north, probably lessening southward, in which direction the ground rises; and on the top of Lady Down there are quarries in nearly horizontal Middle Purbeck beds. At a lower level again, on the southern side of the common, by the lane leading to Chicksgrove, layers of marlstone and oolite like those at Ridge can be seen; and the basement-beds of the Lower Purbeck, with the hard chalky limestone below, cross the lane at its lower end.

Similar oolitic beds are also exposed in the bank at the western end of the lane leading from Chilmark quarries to Teffont, and here they contain the characteristic Lower Purbeck form *Cypris purbeckensis*.

Beds of the same kind were also proved in 1890 below the Middle Purbeck, at the bottom of the large quarry at Teffont Evias.

IV. The Middle Purbeck Group.

One of the best sections in the lower part of the Middle Purbeck group is that to be seen in the quarry west of Teffont Evias church, and in 1890 we had an excavation made below the floor of the quarry for a depth of about 7 feet, in order to prove the nature of the underlying strata. The complete succession then seen was as follows, the names given to the beds by the workmen being printed in small capitals:—

		Feet.	Inches.
Middle Purbeck. 14½ feet.	Soil.		
	Rubble of white limestone	1	0
	Marly shale, with a layer of 'beef' and lenticular seams of chert, crowded with silicified shells of *Cyclas*	1	0
	Rough, greyish, sandy limestone (Cinder-bed), with *Ostrea distorta*, *Trigonia gibbosa*, and a spine of *Cidaris purbeckensis*	1	6
	Yellowish, calcareous, sandy shale	0	9
	Hard, grey, shelly limestone in three courses, with shaly partings; Chelonian bones, *Hybodus*-spines, *Estheria subquadrata*, *Cypridea punctata*, *Cyprione Bristovii*, *Cyprione* sp., and *Metacypris* sp.	2	9
	Dry, buff-coloured, sandy and calcareous shales (Scale) full of small *Modiolæ*; Pycnodont teeth	1	6
	Buff-coloured, marly clay	0	8
	Hard, compact, grey marlstone (White Lias), jointed vertically, no fossils found	2	0
	Dark grey or black shale, with *Mesodon macropterus*, *Estheria Andrewsii*, *Cypridea fasciculata*, and *C. punctata*	0	2
	Hard, grey, shelly limestone, showing ripple-marks and sun-cracks, splitting into slabs which are used as flagstones; *Cypridea fasciculata*, *Cyclas*, fish-vertebræ and scales (Tilestone or Flagstone)	1	6
	Yellowish laminated shale, with layers of crushed shells	0	7
	Brown and black, shaly clay, contains *Cypris purbeckensis* plentifully, *C. fasciculata* (less common), *Estheria Andrewsii?*, *Cyclas*, and scales of *Lepidotus*	1	0
Lower Purbeck. 16 feet 9 inches.	Very hard, compact, grey marlstone (Lias No. 2); fish-remains: *Leptolepis*, *Coccolepis*, and *Pleuropholis*, with *Archæoniscus* and wing-cases of Coleoptera	3	6
	Brown clay	0	6
	Soft, yellowish, marly sand	1	6
	Hard grey marlstone, very heavy (Lias No. 3), with *Cypris purbeckensis*, *Pleuropholis*, insect-remains (Coleoptera and *Libellula*), and plants (*Palæocyparis*)	3	6
	Brown clay (generally the floor of the quarry)	0	4
	Yellowish sandy marl, with oolitic grains and a thin layer of compact marlstone near the top, contains Cyprids (? *purbeckensis*) and Crocodile-scales	2	6
	Grey marly limestone	0	6
	Soft yellowish marl	0	8
	Grey marlstone (or Lias), with vertical jointing	1	3
	Soft sandy marl	0	6
	Hard grey and brown marlstone, compact and heavy, with ochreous patches and markings ... seen for	2	0

In accordance with the classification of the Purbeck series by means of the various species of Cyprids, as proposed by Edward Forbes and confirmed by Prof. T. Rupert Jones, we have taken the line of division

between the Lower and Middle groups at the point where *Cypridea fasciculata* first makes its appearance. This is in the brown and black clay, which is a conspicuous bed in the section, and consequently a convenient plane of division. It is true that *Cypris purbeckensis* is still the most abundant form, so that the bed might be grouped with either division, but we prefer to regard the incoming of *C. fasciculata* as marking the base of the Middle Purbeck Beds.

A quarry south-west of Lower Chicksgrove, on the southern side of the railway, exposes the same part of the series as that seen at Teffont, and there is a very close correspondence between the two sections, in spite of their being 1½ mile apart. The brown and black shaly clay (taken as the base of the Middle Purbeck group) is seen resting on the same marly limestone as at Teffont, but the overlying yellowish shelly shale has thinned out, while the 'Flagstone' has thickened to 3 feet, and forms two courses of hard shelly fissile stone. This bed contains *Cyrena media*, *Paludina carinifera*?, *Cypridea fasciculata*, *Estheria subquadrata*, with branches of *Thuyites* and impressions of long reed-like leaves.

Above the 'Flagstone' comes a thin shale, and then the 'White Lias,' with just the same thickness as at Teffont, namely 2 feet. The overlying beds, including the 'Scale' with *Modiolæ*, are similar; but the succeeding grey shelly limestone is only 1 foot 9 inches thick. It is here a very pure limestone, made up almost entirely of Cyprid and *Cyclas*-shells, *Cypridea fasciculata* and *C. punctata* being abundant.

The 'Cinder-bed' is of much the same thickness as at Teffont, but lies in two courses: a lower course of hard grey marly limestone without *Ostreæ*, but containing a few individuals of *Cyrena* (? *media*), and an upper course, partly hard and partly loose and rubbly, with many fossils, among which *Ostrea distorta*, *Trigonia gibbosa*, and *Cyrena media* are conspicuous.

Above the 'Cinder-bed' come the following in ascending order:—

	Inches.
1. Soft, brown, marly clay and yellowish shaly marl	8
2. Soft grey clay, with a lenticular layer of whitish limestone and a thin layer of 'beef'	9
3. Hard, marly, oolitic limestone with *Cyclas* and *Cyrena*	10

A quarry on Lady Down, about 1 mile north-west of this, carried a similar section to a somewhat higher horizon, the part above the 'Cinder-bed' being as follows (in descending order):—

	Feet.	Inches.
Dark-brown sandy soil	2	0
Traces of limestone, with *Archæoniscus*	0	2
Yellowish, calcareous, gritty sand, with layer of reddish-brown sandstone at the base	0	6
Whitish fissile limestone, in thin layers...............	0	4
Hard shelly limestone, in one massive course	1	3
Compact white limestone, passing down into flaggy oolitic and shelly limestone	1	6
Laminated marly beds, yellowish and brownish, with layers of 'beef' and whitish shell-marl	1	4
CINDER-BED below.		

The section exposed in the railway-cutting, $\frac{1}{2}$ mile south of Teffont and on the southern side of the river, carries the series still higher, and shows also that a certain lateral change takes place in the higher beds as they are followed from west to east. This section is now partially obscured by talus and turf, but was measured by one of us in 1880, when the beds were all clearly exposed along its whole length; and even now, by combining exposures on the northern and southern sides of the cutting, the following descending succession can be made out:—

	Feet.	Inches.
Wet grey and yellow sand	3 or 4	0
Light-grey sticky clay	1	8
Soft marly clays, with thin, brown, iron-stained layers	2	0
Light buff-coloured marl	0	4
Hard, whitish, grey-hearted silty limestone, weathering into angular blocks with vertical fracture	1	0
Soft, laminated, grey and brown, sandy marls and clays, with some shelly layers and a seam of 'beef'	2	0
Rather hard, brown and grey, sandy stone	0	6
Brownish sandy clay, with thin irregular and lenticular seams of sandy limestone	1	0
Hard, buff-coloured, sandy limestone, laminated at top and bottom; contains large *Cyrenæ*	1	0
Soft shaly marl, with crushed shells	0	6
Layer of 'beef'	0	1
Laminated shelly marls, brown, yellow, and whitish, very hard in parts, full of bivalve shells	0	10
Hard, grey, marly limestone (*Archæoniscus*-bed), containing also *Ostrea distorta*, *Corbulæ*, and a *Cardium*	0	6
Grey sandy limestone	0	2
Dark-brown ferruginous sandstone	0	3
Soft sandy limestone	0	2
White fissile limestone, splitting into layers from 1 to 2 inches thick	1	4
Hard shelly limestone, here very thin	0	1
Soft whitish limestone	0	8
Layer of 'beef'	0	2
Soft, laminated, shelly limestone, full of crushed shells	0	6
Chalcedonic chert full of *Cyclas* ...... from 1 inch to	0	3
Brown clay	0	2
CINDER-BED, very hard in places, loose and soft in others; *Ostrea distorta*, *Trigonia gibbosa*, and *Tr. densinoda*	2	6
Hard blue-hearted limestone in two or three courses, with marly partings, *Ostrea* and Univalves	3	0
Yellowish sandy limestone	1	0
Dark clay	0	2
Hard grey marlstone, FIRST LIAS	1	6
Grey clay	0	2
Hard, grey, shelly limestone (the FLAGSTONE)	2	0
	29	6

The above section was described by one of us in 1881, and was accompanied by a diagrammatic view of the vertical succession; but it should be mentioned that this was a generalized view, every bed seen in the cutting being inserted, and was not a vertical section taken at any one point. Thus the shelly limestone underlying the fissile limestone, which was only 1 inch thick where our section was

taken in 1890, is shown in the diagram of 1881 as 12 inches thick; in reality it thickens from 1 to 12 inches westward in a distance of 30 yards, and it is this bed in its expanded form which is touched at the top of the quarry at Lower Chicksgrove, and which is seen to be nearly 3 feet thick in the quarry on Lady Down (p. 54).

On the other hand, the overlying white fissile limestone thickens from west to east, being only 4 inches thick on Lady Down and at least 16 inches in the railway-cutting. The lower white limestone seems to be a local bed which thins out in both directions. The diagram (fig. 2, on the opposite page) shows the variations in the strata between the two well-marked horizons of the 'Cinder-bed' and the *Archæoniscus*-limestone at the two localities mentioned, and at a third one still farther east.

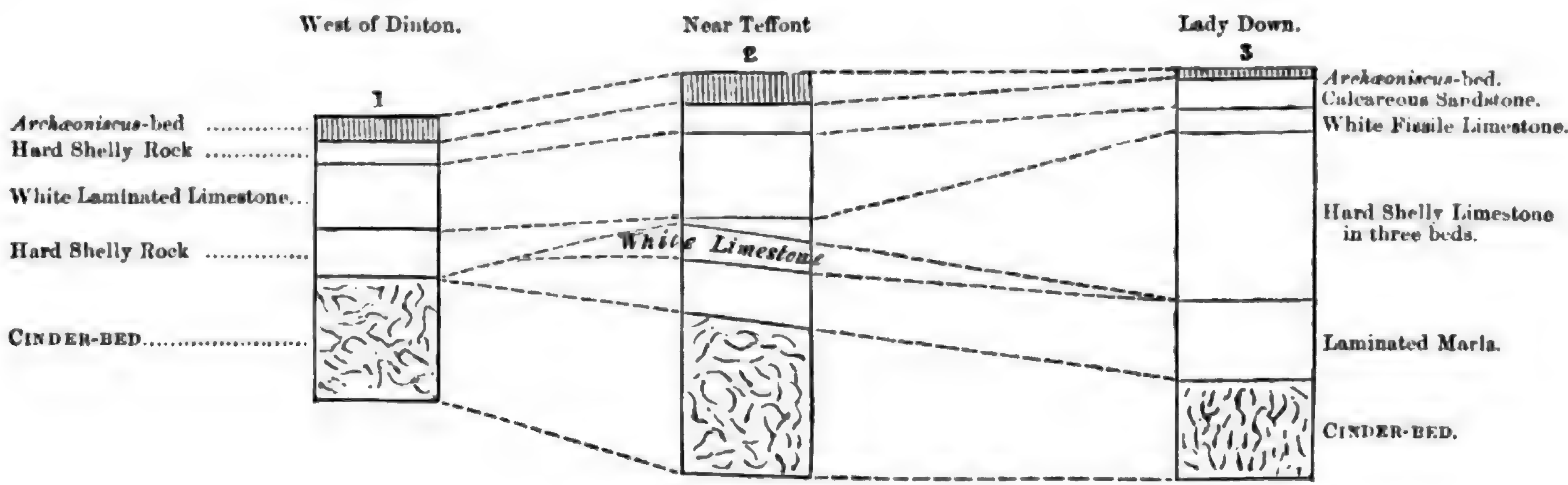
We now come to the most easterly exposures near Dinton Station, where the eastward dip brings in still higher beds and ultimately those which we believe to be of Upper Purbeck age. The cutting which runs through a wood, and commences about 700 yards west of Dinton Station, has been quarried back for stone and exposes the same part of the series as that seen in the middle of the larger cutting to the west, but several of the beds have thinned out, so that the space between the 'Cinder-bed' and the topmost sands is greatly contracted. The lower part of this section from the *Archæoniscus*-bed downward is given in fig. 2; above that horizon the following beds are seen in the eastern corner of the old quarry:—

	Feet.	Inches.
Sticky grey clay, seen for	0	6
Brownish clay, passing down into whitish marly clay with irregular lumps of hard shelly limestone at intervals	1	0
Layer of fibrous carbonate of lime ('beef') up to	0	2
Layers of grey shaly clay, sandy shale, and yellow sand, with crushed shells	2	6
Lenticules of sandy limestone and 'beef' in brownish sandy shale	0	6
Hard, buff-coloured, sandy limestone, solid in the upper part, laminated in the lower part	1	0
Brown sandy shale and clay, with crushed shells	0	8
Hard, crystalline, shelly limestone	0	1½
Compact, grey, marly limestone (*Archæoniscus*-bed) with many specimens of *Archæoniscus*	0	4
	6	9½

These beds dip south-eastward and appear to pass below a thick bed of clay which is now grassed over, but seems to be about 8 feet thick; this is overlain by soft yellow sand with a thin surface-covering of gravel, the two together often slipping over the clay. The cutting then ends, and the ground falls to a little watercourse, which passes under the railway about 400 yards west of the station.

We take this clay and sand to be the basement-beds of the Upper Purbeck group, but we are by no means sure that they are in direct succession to the beds above described. If the section just given be

Fig. 2.—*Diagram showing variations in the strata between the Cinder-bed and the* Archæoniscus-*limestone.*



Vertical scale: 1 inch = 4 feet.

compared with that of the cutting south of Teffont (p. 55), it will be seen that the succession is similar for about 6 feet above the *Archæoniscus*-bed: the variations are only such as might well occur in the space of a mile, and are probably in part due to the individual layers being differently grouped by ourselves. South of Teffont cutting, however, there is a whitish limestone succeeded by about 4 feet of marly clay, followed by yellow sand; at first sight we took the clay and sand to be the same as those of the Dinton cutting, and inferred that the whitish limestone had thinned out eastward, but subsequently we saw reason to doubt this correlation on the following grounds.

In the wood south-east of the quarried cutting near Dinton there are old stone-workings now overgrown, but at the bottom of this wood the *Archæoniscus*-bed and the overlying sandy laminated limestone crop out in the river-bank near the sluice-hatches. They are doubtless carried down to this low level by the south-easterly dip; but, in order to see what beds could have been quarried here *above* the *Archæoniscus*-limestone, we had a trench cut down the bank of the old quarry on the north-eastern edge of the wood, and in this were exposed the following beds:—

	Feet.	Inches.
Yellow and grey sand, with lumps of brownish calcareous sandstone containing *Cyrena* and *Melanopsis*; thin layers of grey clay occur in the lower part, which passes down into the next...	2	0
Stiff grey clay, with thin layers of grey sand and thicker layers of yellow sand	1	0
Stiff grey clay, yellowish near the base	2	0
Hard, whitish, silty limestone, breaking vertically into sharp splintery fragments	0	5
Soft, buff-coloured, shaly marl with *Cypridea punctata*	0	7
Hard, buff-coloured, grey-hearted, sandy limestone	0	7
Flaggy and shelly stone, with layers of 'beef'	0	4
Grey marly clay, with layers of whitish shell-marl	1	0
Sandy and shelly limestone with *Cyrena*	0	4
Floor of hard stone.		
	8	3

These beds are quite different from any exposed in the railway-cuttings near by; but the hard, whitish, splintery limestone is not unlike the whitish limestone which occurs about 8 feet from the top of the deep cutting south of Teffont (p. 55). We are strongly inclined to think that the beds visible in the trench are the equivalents of those seen at the top of the above-mentioned cutting, and that they lie below the thick blue clay and yellow sand of the Dinton cutting, being there cut out by a fault, which crosses the railway-line where the stone beds end abruptly. If this be so, the thickness of the strata between the *Archæoniscus*-limestone and the thick blue clay is some 8 or 10 feet greater than it appears to be in the Dinton cutting, and these beds must be added to the Middle Purbeck group.

V. The Upper Purbeck Group.

As stated on p. 56, we take the thick bed of clay seen in the quarry-cutting west of Dinton to be the base of the Upper Purbeck group. We do so, more for the sake of convenience than for any resemblance to beds elsewhere; but the soft and purely siliceous sand which overlies the clay is a conspicuous bed, capable of identification if exposed at other localities. A slip in the southern bank of this cutting in October 1890 showed the following section:—

	Feet.	Inches
Gravel	3 to 4	0
Yellow sand, with seams of grey sandy clay from ½ inch to 4 inches thick	1	6
Yellow and brown sand, in alternating layers (base not seen)	8	0
Wet grey sand, passing down into silty clay		......
Stiff grey clay at the base.		

We may, therefore, assume that there is at least 10 feet of the sand in this cutting.

East of the watercourse and cattle-creep there is another cutting almost entirely grassed over, but its western end does not seem to be in sand, as it would be if the south-easterly dip were continued; and moreover the first beds seen are dipping westward, so that we suspect there is a line of fault between the two cuttings.

A hard shelly limestone crops out in the bank at intervals, rising eastward; and at a point about 80 yards east of the watercourse we made a narrow trench down the bank, finding the following beds in the lower two-thirds of the slope:—

	Feet.	Inches.
'Beef' (fibrous carbonate of lime)		3
Brown sandy clay		4
Soft, calcareous, shelly marl		6
Stiff blue clay		9
Sandy clay, with layers of 'beef'		4
Grey shaly clay		3
Soft yellow marl, with crushed shells		8
'Beef' (1 inch) and brown sandy clay		4
Hard shelly limestone, grey inside, weathering yellowish; with *Unio*		6
Buff-coloured or brownish nodular limestone, with *Cyrena media* and *Paludina*		3
'Beef' and sandy stone		4
Yellow and grey sand, with a log of endogenous wood in place	3	0
	7	6

The soft sand at the bottom we consider to be the same as that seen at the top of the western cutting, and as the overlying beds contain *Cyrena*, *Paludina*, and *Unio*, we are inclined to regard them as the equivalents of the *Unio*-beds of the Dorset series. If our reading of these partially obscured sections be correct, the eastern cutting traverses an anticlinal flexure, the western limb of which is faulted against the beds seen in the other cutting. We assume, in fact, that the strata are broken by two faults, each with a downthrow to the east as shown in the section on the next page (fig. 3).

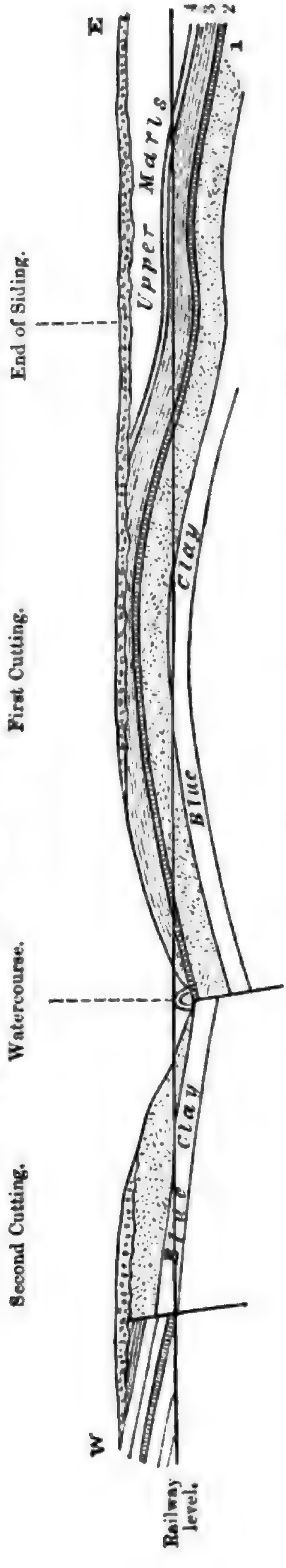


Fig. 3.—*Section along the Railway, west of Dinton Station.*

Scale: horizontal, 1 inch = 75 yards; vertical, 1 inch = 80 feet.

1. Yellow Sand.
2. Limestone.
3. Marls and Clays.
4. Two layers of Calcareous Grit.

From the place where the above succession was measured the shelly limestone can be traced in the bank, at first rising and then falling eastward to the level of the rails. The other beds doubtless come in above, and where the bank is cut back for the railway-siding a different set of beds is exposed, dipping at an angle of 18° to N. 30° E. The section is:—

		Ft.	In.
Upper Purbeck.	13. Loam and gravel...	4	0
	12. Light-grey marly and silty shale ...	4	0
	11. Grey clays, with thin layers of yellow sand	2	0
	10. Grey marly clay ...	1	0
	9. Hard, dark-grey, calcareous grit...		2
	8. Sandy marl		2
	7. Yellowish marly limestone, breaking vertically ...		5
	6. Yellow marly clay, passing down into dark-grey shale .		6
	5. Hard, dark-grey, calcareous grit...		3
	4. Light bluish-grey clay		6
	3. Grey and brown sandy marl, with stony nodules near the top......		9
	2. Grey sandy marl, with thin layer of 'beef'		3
	1. Yellowish-white shelly marl		9
		14	9

With the exception of the lowest stratum of shelly marl, these beds are quite different from any seen elsewhere in the Vale of Wardour. We found Cyprids in the beds numbered 5, 6, 7, and they were identified by Prof. T. Rupert Jones as *Cypridea punctata*, with the addition of *Cyprione Bristovii*

in the dark shale. Nothing like *Cypridea fasciculata* occurred in any of the beds.

The dip being steep, it is not surprising to find that a great thickness of Upper Purbeck clays comes in to the eastward within a very short distance. Three hundred yards north-east of the above section are some cottages, where a well was sunk in 1884. From the account of the well-sinker, and from examination of the material thrown out, this well seems to have proved the following beds:—

	Feet.
Yellow clay	3 or 4
Light-grey silty marl	11 or 12
Stiff grey clay	5 or 6
Very stiff, grey and brown clays	about 20
Hard gritty stone at the bottom; this being punched through, water rose at once	a few inches
	about 40 feet.

In the material thrown out and coming from the stiff grey clays, one of us found *Paludina carinifera*, an *Unio*, some fish-scales, and many Cyprids, the last-mentioned being identified by Prof. T. Rupert Jones as *Cypridea punctata* and a smooth variety like *C. valdensis*, *Cyprione Bristovii*, and *Darwinula leguminella*. A specimen of the bottom stone-bed was also obtained, and proved to be exactly like the layers of hard calcareous grit seen in the railway-siding; it also contained *C. punctata*, and we have little doubt that it is the upper of the two calcareous grits.

How much farther the Upper Purbeck Beds extend eastward and north-eastward we were unable to ascertain. There are only low-lying fields in that direction, the ground is obscured by a gravelly soil, and the railway passes on to the alluvium. We think, however, that the yellow Wealden Clays come in a very few yards north of the well.

On the southern side of the river, in a field near Catherine Ford, which is due south of Dinton Station, a shallow well has recently been dug (1892) and exposed beds like those seen in the railway-siding, namely:—

	Feet.	Inches.
Loam and gravel	3	0
Marl	2	0
Dark-grey grit	0	2
Grey marly clay	1	0
Dark-grey grit	0	3
Red sandy marl	3	0
Hard grey marl	1	3
	10	8

There are three other localities where some of the beds which we have classed as Upper Purbeck seem to be present, but unfortunately no clear sections are exposed. One is on the high ground south of the railway-cutting and north-east of Daslett Farm. Another is on the rising ground south of the quarry in the Middle

Purbeck at Lower Chicksgrove; the highest ground here consists of grey shaly clay which is exposed by the roadside, and may be the thick clay which we take as the base of the Upper Purbeck; the ground then dips into a hollow where higher beds may occur, but, as the general dip here seems north-easterly, this is doubtful. This very north-easterly dip, however, makes it possible that Upper Purbeck Beds come on in that direction, and the anomalous beds seen in an old quarry and in the railway-cutting by Chicksgrove Farm may possibly belong to the Upper, and not to the Middle group.

The third locality, where beds higher than those we have grouped are present, is north of Ley Farm and south-west of Teffont Evias. Here the soil is very sandy, and pieces of endogenous wood (*Endogenites*) frequently occur in it. We have little doubt that there is here an outlier of the thick sand seen in the cuttings near Dinton, and immediately north of Ley Farm there is a spring—which is suggestive of a substratum of clay.

In the first instance, and before we found sand containing *Endogenites* overlain by beds of distinctly Purbeck character at Dinton, we took these and other outlying patches of sand to be remnants of the Hastings Sands. Now, however, we do not believe that there is any representative of the Hastings Sands in the Vale of Wardour: the other sandy outliers resting on Lower Purbeck belong probably to the Vectian Sand, which overlaps the narrow strip of Wealden Clay.

Those who are acquainted with the literature of the Purbeck Beds and their contents will doubtless observe that, in the preceding stratigraphical account, no mention has been made of the 'Insect-bed' discovered and described by the Rev. P. B. Brodie, F.G.S. This omission is not due to any neglect on our part, for we have lost no opportunity of searching for traces of such a bed, and have sought Mr. Brodie's assistance in ascertaining the exact position of the old quarry where the Insect-limestone occurred.

Mr. Brodie found the place so altered, when he visited the spot with Mr. Andrews in 1888 after the lapse of more than 40 years, that he was unable to recognize the exact site of the quarry, but it was "at the bottom of the field opposite the railway-station, not far from the road, and near the river." There is a pond in the position thus indicated: it is possible that this is on the site of the quarry, and that the *Archæoniscus*-bed is here brought up by the anticlinal seen in the railway-cutting. Mr. Brodie informs us that the limestone of the 'Insect-bed' was stacked in some quantity at the time of his first visit (in 1840), and it had without doubt been quarried from below the level of the water which then occupied the bottom of the quarry: the *Archæoniscus*-bed, or, as he calls it, the 'Isopod-limestone,' being visible above the water-level.

In a later paper[1] Mr. Brodie gave a section taken by the Rev. O. Fisher in a quarry on the south side of the river Nadder, near Teffont Mill, where a laminated limestone does occur in the position

[1] Quart. Journ. Geol. Soc. vol. x. (1854) p. 476.

assigned to the Insect-bed, but it does not appear that any insects were found in it at that locality.

When Mr. Brodie first visited the Vale of Wardour few exposures of the strata were to be seen, and he had no idea that the whole Purbeck series was there represented. In his later paper he states that when he collected from these beds he regarded "the Insect- and Isopod-limestones as belonging to the *lower* part of the *Lower* Purbecks." It was in this way that he came to consider the highest bed of 'lias' in the Middle Purbeck at Teffont as the equivalent of the Isopod- and Insect-limestones, though he notes the lithological difference of the rock and the fact that it only contains a few insects.[1]

It would appear, therefore, that the bed from which Mr. Brodie obtained the greater number of his insect-remains occurs in the upper part of the Middle Purbeck, just beneath the Isopod or *Archæoniscus*-bed; but as we have failed to find any insectiferous limestone at this horizon in the numerous sections which are now open, we are compelled to conclude that it is a stratum of local occurrence, confined to a very small area in the most easterly part of the Vale of Wardour, a view in which Mr. Brodie now concurs.

VI. General Conclusions, and Comparison of Dorset and Wiltshire Purbecks.

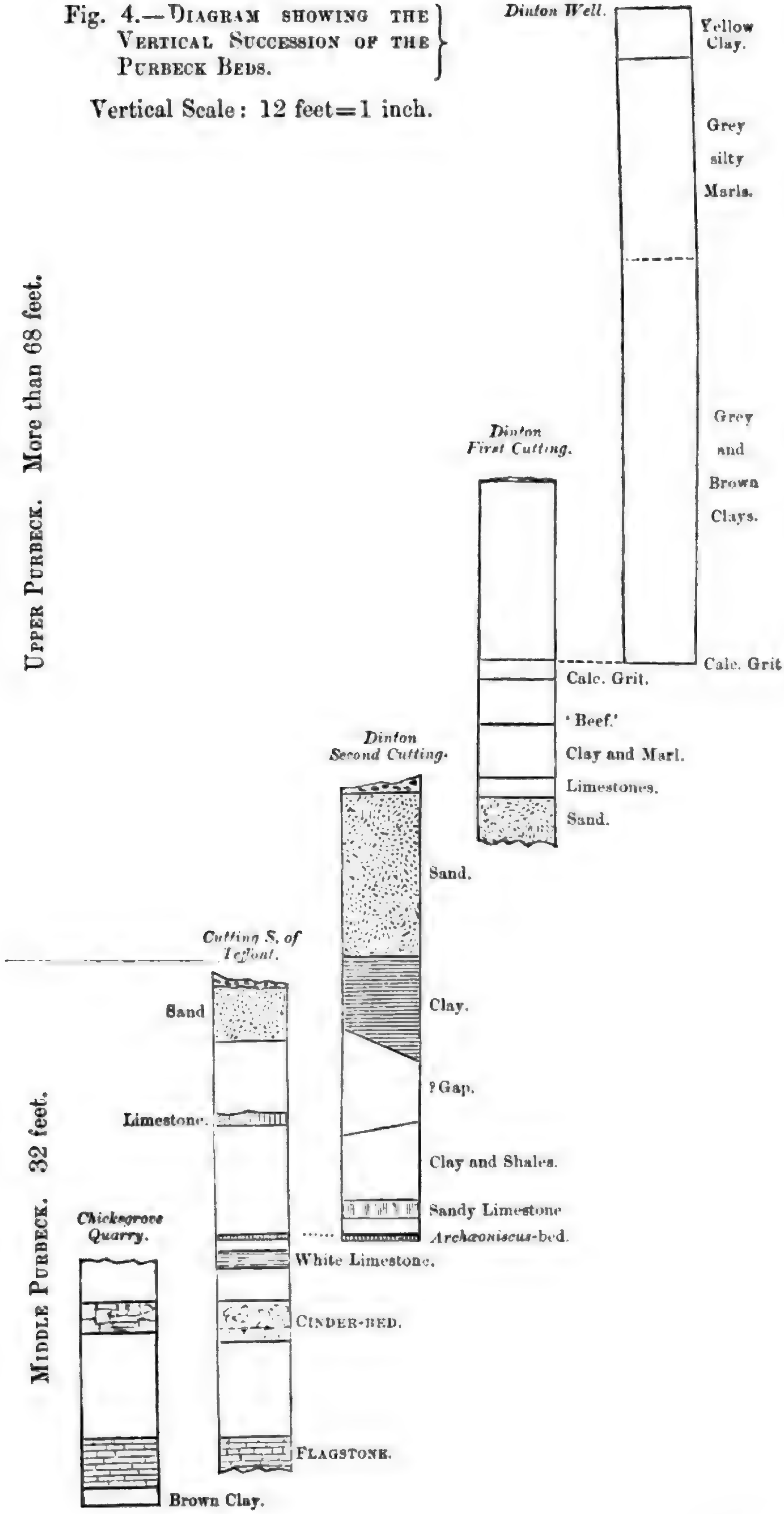
From the sections given in the preceding pages it will be seen that we have now better data than previously existed for calculating the thickness of the several parts of the Purbeck series in the Vale of Wardour. There is still some difficulty in fitting in all the exposed sections with one another, and we have not found the actual summit of the formation; but we think that there are not many of its component beds which we have not seen, and that our estimate of the total thickness will be found a near approximation to the truth.

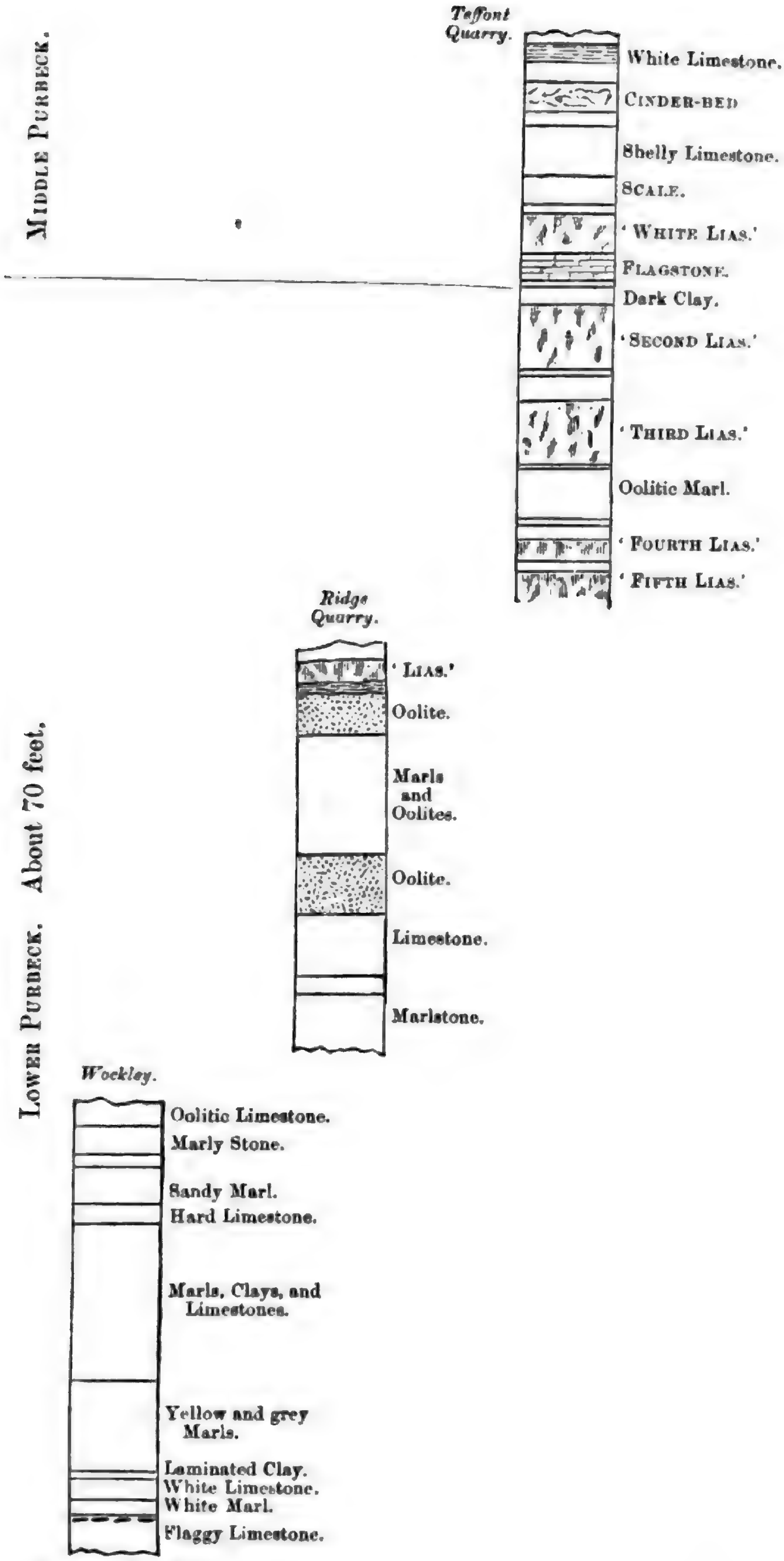
Lower Purbeck.—If we take the Wockley section, which is repeated at Chicksgrove, as giving the more prevalent type of the basement-beds, we have there from 22 to 24 feet of Lower Purbeck, and in the Ridge quarry there are over 21 feet (see pp. 49, 52). It is clear that these two sections do not overlap, and how much comes in between them we cannot say; but in the lane from Chicksgrove to Lady Down there is quite room for 60 or 70 feet between the basement-bed and the outcrop of the oolitic beds. Finally, nearly 17 feet of strata occur in the Teffont quarry which seem to be above any exposed at Ridge; consequently we have actually seen over 60 feet of Lower Purbeck beds, and, allowing for the gap between the Ridge and Wockley sections, we consider that 70 feet is a fair estimate of their average thickness. The diagram on p. 65 (fig. 4) shows the vertical succession which is assumed in this estimate:—

[1] See 'Fossil Insects,' pp. 18, 19.

Fig. 4.—Diagram showing the Vertical Succession of the Purbeck Beds.

Vertical Scale: 12 feet=1 inch.




Teffont Quarry.
White Limestone.
CINDER-BED
Shelly Limestone.
SCALE.
'WHITE LIAS.'
FLAGSTONE.
Dark Clay.
'SECOND LIAS.'
'THIRD LIAS.'
Oolitic Marl.
'FOURTH LIAS.'
'FIFTH LIAS.'
MIDDLE PURBECK.
Ridge Quarry.
'LIAS.'
Oolite.
Marls and Oolites.
Oolite.
Limestone.
Marlstone.
LOWER PURBECK. About 70 feet.
Wockley.
Oolitic Limestone.
Marly Stone.
Sandy Marl.
Hard Limestone.
Marls, Clays, and Limestones.
Yellow and grey Marls.
Laminated Clay.
White Limestone.
White Marl.
Flaggy Limestone.

Middle Purbeck.—Basing this upon the brown and black clay seen at Teffont and at Chicksgrove, it will be found that, though the thicknesses of individual beds in the two sections vary, the vertical distance from the basal clay to the top of the Cinder-bed is almost exactly the same in both, namely, a little over 12 feet. The great cutting on the line south of Teffont shows 19 feet of strata above the Cinder-bed, and if these lie entirely below the clay and sand of the Dinton cutting there is that much (and possibly more) to be classed as Middle Purbeck, for we have no complete section of this part of the series. A total thickness of 32 feet is therefore probably below the mark.

Upper Purbeck.—The clay and sand in the Dinton cuttings must be from 18 to 20 feet thick, and between the top of this sand and the top of the second seam of calcareous grit there is at least a thickness of 8 feet. This grit forms the floor of the Dinton well, which is about 40 feet deep. Hence there is at least 66 feet of this division, and how much more lies beyond we do not know—probably more than 2 and less than 12 feet; but, taking the former figure, we have a minimum thickness of 68 feet.

Putting the estimated thickness of the three divisions together, we have—

Upper Purbeck	68 feet.
Middle Purbeck	32 „
Lower Purbeck	70 „
	170 feet.

Considering the distance that intervenes between the Vale of Wardour and the coast of Dorset (about 32 miles), it is really remarkable that in a set of estuarine and freshwater strata there should be so close a correspondence between the two series that many of the subdivisions which have been recognized in the Dorset sections can also be distinguished in Wiltshire. The Wiltshire Purbeck strata do not in fact differ from the typical facies of Durleston Bay to any greater extent than those of the Upwey (or Ridgeway) section do.

The first point of similarity is that within the small area of the Vale of Wardour the basement-beds show a variation similar to that which occurs in Dorset, but only at sections some distance apart. The basement-beds at Chilmark resemble the 'Cap' of the Isle of Purbeck, but the basement-beds at Chicksgrove and Wockley resemble those at Upwey, where the lowest Purbeck bed is a limestone about 1 foot thick, separating into three layers, the highest of which contains fish-remains (*Histionotus breviceps*), the second a large *Archæoniscus*, and the lowest Cyprids and *Paludina*. This rests on soft, sandy limestone-with-flints, so that the succession is not the same, although similar.

The next noticeable resemblance is the occurrence of broken-up limestone and contorted marls, which seem to occupy the place of the 'Broken Beds' of Dorset. These are also succeeded by a set of beds in which *Cypris purbeckensis* is abundant, and are therefore comparable with the '*Cypris*-freestones' of Dorset. The Ridge beds, with their abundance of *Cardium*, *Corbula*, *Leda*, and *Serpula*,

are evidently the equivalents of the 'Cockle-beds' and especially resemble those of the Upwey (Ridgeway) section, where there is much more limestone than marl and where one of the limestones is described as 'oolitic-looking.' The Upwey 'Cockle-beds' also contain small forms of *Cardium*, *Corbula*, *Leda*, and *Serpula*, which are probably the same species as those found at Ridge. There was evidently a widespread irruption of the sea at this particular epoch, converting the freshwater lakes of the *Cypris*-freestones into saltwater lagoons.

The highest beds of the Lower Purbeck, with their *Cypris purbeckensis*, insect- and fish-remains, show that freshwater conditions were once more predominant, the marls, marlstones, and oolites of the Vale of Wardour being clearly the equivalents of the 'Marly Freshwater Beds' of Dorset.

At the base of the Middle Purbeck group there is a set of beds (between 10 and 11 feet thick) which are not unlike those of the Cherty Freshwater group at Durleston Bay, except that they do not contain chert. They have a similar black and brown clay at the base, and they contain a flaggy shell-limestone of the same character as the lowest beds worked in the Durleston quarries. At Upwey this group is only from 5 to 6 feet thick, and does not contain limestone.

The 'Cinder-bed,' or oyster-limestone, occupies its usual position, and is often crowded with *Trigoniæ* as well as *Ostreæ*. The succeeding beds vary much in Dorset, and the same seems to be the case in the Vale of Wardour, so that no special horizon above the Cinder-bed is recognizable. We may, however, notice one point of resemblance between the Upwey and Wiltshire sections, and that is the prevalence of sand and sandy stone in the group which seems to be the equivalent of the '*Corbula*-beds,' but which in Wiltshire would be more suitably termed the '*Cyrena*-beds.'

As regards the Upper Purbeck group, there is no really clear section of it, so that we cannot be quite sure that all its component beds have come under our notice. We are, however, fairly certain that there are no hard limestones like those of the 'Broken Shell-limestones' which form the base of the group in Dorset. These appear to have thinned out northward, so that the representatives of the *Unio*-beds come to lie at the base of the group, and these only contain very thin limestones. The thick bed of clay which we take as the basement-bed, and the soft yellow sand with *Endogenites* which overlies it, seem to be quite peculiar to the Wiltshire succession. They appear to indicate an episode of what may be termed Wealden conditions, the influx of rapid currents bringing down mud and sand, and temporarily preventing the formation of limestones or marls. This is only what might be expected to occur on the margins of the Purbeck basin.

The highest beds seen in the railway-siding and in the well at Dinton bear much resemblance to the shales and clays of the 'Upper *Cypris*-marls,' and here again the absence of *Paludina*-limestones is worth noting.

Taken as a whole, the Wiltshire series has a greater resemblance to the strata seen in the Upwey or Ridgeway section than

to any other of those in Dorset. The total thickness at Upwey and in the Vale of Wardour is about the same; there is a similar absence of thick limestones, and a singular prevalence of sandy matter in certain parts of the series: resemblances which suggest that the two localities were about equally distant from the borders of the Purbeck area of deposition, the one from the western, the other from the northern border. If the rate of diminution of thickness can be regarded as any guide to the extent of this area, its western limit must have lain within 16 miles of Upwey on the west and within 20 miles of Teffont on the north. It would be very interesting to know whether Purbeck Beds exist beneath the Vale of Pewsey, for we agree with Prof. J. F. Blake in doubting whether the so-called 'Purbeck' of Swindon is coeval with the true Purbeck of Wiltshire and Dorset.

VII. List of Fossils.

The following list is by no means an exhaustive one: it includes such fossils as we were able to obtain from time to time, but we did not collect or attempt to identify all the small bivalves (? *Cyclas*) which crowd some of the beds, and the 'Cinder-bed' of Lower Chicksgrove would probably repay more persevering search than we were able to bestow upon it. We are indebted to Mr. A. Smith Woodward, of the British Museum (Nat. Hist.), for examining and naming the fishes, and to Messrs. G. Sharman and E. T. Newton for identifying some of the mollusca.

	Lower	Middle	Upper
		Purbeck.	
Reptilia.			
Theriosuchus pusillus, Owen	...	*	
Pleurosternum (*ovatum* ?), Owen	...	*	
Pisces.			
Asteracanthus verrucosus (spine), Egert.	...	*	
Hybodus strictus, Ag. (spine)	...	*	
Shark's teeth, vertebræ, and scales	...	*	
Coccolepis Andrewsi, Traq., MS.	*		
Leptolepis Brodiei, Egert.	*		
Mesodon macropterus[1] ?, Ag.	...	*	
Lepidotus (*minor* ?), Ag.	...	*	
Oxygonius tenuis, Ag.	* ?		
Ophiopsis breviceps, Egert.	*		
„ *penicillatus*, Ag.	*		
Macrosemius, sp. nov.	...	*	
Pleuropholis longicauda, Egert.	*		
„ *attenuata*, Egert.	*		

[1] [Mr. A. Smith Woodward kindly informs us that this species has not hitherto been recorded from Britain. The type occurs in the Lithographic Stone of Solenhofen, and though the Wiltshire specimen is much smaller (probably dwarfed by local conditions) he cannot otherwise distinguish it. He also finds a new fish among those sent to him; this is related to *Macrosemius pectoralis*, Sauvage, from the Portlandian of France.—Jan. 12th, 1894.]

LIST OF FOSSILS (*continued*).

	Lower	Middle	Upper
		PURBECK.	
Gasteropoda.			
Melanopsis Popei, Forbes, MS.	...	*	
Paludina carinifera, Sow.	...	*	*
" sp.	...	*	
Valvata helicoides, Forbes, MS.	*		
Lamellibranchiata.			
Cardium morinicum, De Lor.	*		
" sp.	...	*	
Cyrena media, Sow.	*	*	*
" *parva*, Sow.	...	*	
Corbula alata, Sow.	*		
Modiola, sp.	...	*	
Ostrea distorta, Sow.	...	*	
Leda, sp.	*		
Perna, sp.	*		
Gervillia or *Avicula*, sp.	...	*	
Trigonia gibbosa, Sow.	...	*	
" *densinoda*, Eth.	...	*	
Unio (*compressus*?), Sow.	...	...	*
Crustacea.			
Archæoniscus Brodiei, M.-Edw.	...	*	
Candona ansata, Jones	*		
" *bononiensis*, Jones	*		
Cypris purbeckensis, Forbes	*		
Cypridea fasciculata, Forbes	...	*	
" *punctata*, Forbes	...	*	*
Cyprione Bristovii, Jones	...	*	*
Darwinula leguminella, Forbes	...	...	*
Estheria elliptica, Dunk., var. *subquadrata*, Sow.	...	*	
Estheria Andrewsii, Jones	...	*	
Insecta.			
Libellula, sp. (wing)	*		
Coleoptera (wing-cases)	*		
Echinodermata.			
Hemicidaris purbeckensis, Forbes	...	*	
Plantæ.			
Cycadeoidea microphylla, Buckl.	*		
Equisetites (*Clathraria*) *Lyellii*, Mant.	...	*	
Coniferous wood	*	*	
Palæocyparis	*		
Reed-like leaves	...	*	

Discussion.

The President said that the Society was much indebted to the Authors, and especially to Mr. Andrews, for details as to these beds which he alone could furnish. He (the President) had often received assistance from Mr. Andrews when he was working at the Portland Beds of the Vale of Wardour, but that gentleman could never interest him in the Purbecks of the locality—a somewhat monotonous series, with fossils too often flattened to be recognized. The difficulties of investigation were considerable; hence the old view that the Wardour Purbecks did not exceed 70 feet, whereas the Authors considered that they had demonstrated a thickness of 170 feet. In the Vale of Wardour there were no fine cliff-sections as in Durleston Bay, and the entire series had to be constructed by piecing together the exposures in different quarries.

The Authors had adduced additional palæontological evidence, which, in his opinion, tended to strengthen the view that the Purbeck, taken as a whole, could scarcely be called a freshwater formation. Inroads of the sea were perpetually replacing the freshwater fauna by estuarine or marine forms, and such species as *Trigonia gibbosa* and *Cardium morinicum* seemed to indicate that a Portlandian fauna was close at hand. Both in the Lower and Middle Purbeck Beds these marine horizons were well-marked, and it was extremely interesting to find that the Authors could correlate them with the developments in Dorset. The most novel feature was the discovery of Upper Purbeck strata: these sandstones with *Endogenites* had little in common with the Upper Purbeck of Dorset, and had usually been regarded as of Wealden age. Indeed the Authors admitted that the conditions were Wealden, but the Cyprids, as determined by Prof. T. Rupert Jones, were held to indicate Purbeck affinities.

Prof. J. F. Blake remarked on the great value of the paper. He had not been able to accept the idea of the junction with the Portland being in the middle of a block, and was glad to find that the Authors also declined to accept this line. On general principles he considered that, unless there was a physical change accompanying a faunal one, the latter was of secondary importance. Palæontology must be the servant and not the master of Geology. He thought the Purbecks of the Vale of Wardour were really locally unconformable on the Portlands, and had been laid down in a separate lake or estuary not directly connected with that of Dorset. He enquired as to the overlying Cretaceous rocks, because on their conformability or otherwise would depend the Upper Purbeck or Wealden character of the highest beds described.

Prof. T. Rupert Jones, in explanation of the conditions of the Lowest Purbeck 'flaggy limestone' and its conterminous strata, thought that the Portlandian sea, in giving way to the shallowing of the coast, and the local predominance of freshwater lagoons, must have been rough enough at times to break up the changing floor, disturb the new deposits, and make a kind of unconformity, accom-

panied sometimes by the quiet intermixture of marine and fresh-water forms of life. As the lagoons communicated with one and the same sea, it is not surprising that nearly similar conditions of strata and of fossils should be found to exist, in approximately uniform succession, wherever the Purbecks are now opened out.

The genus *Cypridea* occurs throughout the Purbeck series, and has an ally now living in the Lake of Geneva. That the leading species in the Upper Purbeck (*Cypridea punctata*) is closely allied to the next following form (*C. valdensis*, of the Wealden Beds) there is no doubt; but it is distinct. The finding of *Endogenites erosa* in place in the Wardour Purbeck clears up some doubts about the relics of that fossil having been found near Hartwell, Bucks.

Mr. H. B. Woodward remarked that in his original section at Dinton (Quart. Journ. Geol. Soc. vol. xxxvii. 1881, p. 251) Mr. Andrews had taken the Wealden boundary at a lower level, and had considered that the Upper Purbeck Beds were absent. He was inclined, however, to agree in part with that interpretation of the section, believing that the coloured clays and sands with *Endogenites* should be classed as Wealden. Even on this view there was no evidence to show that Upper Purbeck Beds were unrepresented. He had no faith in fixing a plane of demarcation between the Purbeck and Wealden Beds by means of ostracoda.

By permission of the President, he read extracts from a letter of the Rev. P. B. Brodie, who desired to state that "When I first visited the Vale of Wardour there were but few available sections, and, as a young geologist, I naturally followed the lead of so able a one as Dr. Fitton. All this was more than half a century ago. Since then Mr. Andrews' fortunate residence in the district, and the fine section exposed in the railway-cutting near Teffont, has enabled him and Mr. Jukes-Browne to study far better sections than either Fitton or myself had seen, and hence their decision is no doubt correct as to the stratigraphical divisions which they now propose."

After alluding to the interesting paper by the President (1881) in connexion with an excursion of the Geologists' Association, Mr. Woodward observed that the pre-Cretaceous folds in the Purbeck and Portland Beds, to which the Authors had drawn attention, might be compared with those affecting the Jurassic rocks in the Weymouth and Purbeck area, which Mr. Strahan had lately interpreted in carrying out the Government geological survey.

The Rev. W. R. Andrews, in reply, said that the threefold division of the Purbeck by Forbes, based on the ostracoda, had been fully borne out by the investigations of Prof. T. Rupert Jones. The yellow Wealden Clay overlies the Upper Purbeck, but does not always rest on the same bed. This the speaker explained by pre-Cretaceous earth-movements. He thanked the Society, on his own behalf and on that of his colleague, for the manner in which their paper had been received.

6. *On some* BRYOZOA *from the* INFERIOR OOLITE *of* SHIPTON GORGE, DORSET. Part II.[1] By EDWIN A. WALFORD, Esq., F.G.S. (Read April 12th, 1893.)

[PLATES II.–IV.]

THE Cheilostomatous Bryozoa have hardly been recognized with certainty in the Jurassic series, and Haime mentions two forms of the Escharidæ in his monograph[2] with considerable doubt and without illustration. In the little group dealt with in this paper are mingled both cheilostomatous and cyclostomatous features, but the former predominate, and, for the present, it is desirable to place the group there. We thus open a field for investigation which will trench deeply into the ground hitherto occupied by the Cyclostomata.

Messrs. Waters, Vine, and Ulrich have written of cheilostomatous structure in Palæozoic fossils; the English Jura now leads backward also the relations of this sub-order, and we need to scan this distant horizon of bryozoan development for signs sufficient to guide us on our way.

After I had read Part I. of my paper in 1889 I withdrew for further study two of the species related to those that I am about to describe. So many of their features were dissimilar to the Entalophora among which I had placed them, similar as they were in general aspect, that it seemed necessary to find a place for them elsewhere.

The characters of the two sub-orders Cheilostomata and Cyclostomata merge as we pass backward in time. This merging the accessory organs of the genus and species here described and figured will illustrate. Mr. A. W. Waters has paved the way to the same conclusion in a recent paper.[3] He writes:—'In the Cretaceous Melicertitidæ the characters are in the main chilostomatous united with some that are cyclostomatous, and also in a very large section of Palæozoic fossils there are important structures similar to those in recent Chilostomata."

It may ultimately be necessary to erect a new sub-order for the association of these intermediary forms. When, however, we understand better the various stages of growth and eccentricities of arrangement of cells, then perhaps the number of genera and species we have made and are making may be pruned to as moderate a growth as that to which Dr. Ed. Pergens, in his laborious work,[4]

[1] For Part I., see Quart. Journ. Geol. Soc. vol. xlv. (1889) pp. 561–574, pls. xvii.–xix.

[2] 'Descr. des Bryoz. Foss. de la Form. jurass.,' Mém. Soc. Géol. France, sér. 2, vol. v. (1854) p. 217.

[3] 'On Chilostomatous Characters in Melicertitidæ and other Fossil Bryozoa,' Ann. & Mag. Nat. Hist. ser. 6, vol. viii. (1891) pp. 48–53, pl. vi.

[4] 'Revision des Bryoz. du Crétacé figurés par d'Orbigny, 1ère Partie—Cyclostomata,' Bull. Soc. Belge de Géologie, vol. iii. 1889 (Mémoires), pp. 305–400.

has so far reduced the prodigality of d'Orbigny's nomenclature. And yet I write this after giving my leisure hours of the past three years to the study of the new genus *Pergensia*, so named in recognition of Dr. Pergens's labour of revision.

[Since the reading of this paper I have been aided by the gift of specimens from Miss E. C. Jelly, the author of a most valuable 'Synonymic Catalogue of Recent Marine Bryozoa.' *Lekythopora* and *Pæcilipora* have many points of relationship with the new genus *Pergensia*. To the general family likeness to the Celleporidæ I had previously drawn attention, in a comment upon the rostra and apertures of one form.

The globose ovicell-sacs of *Pergensia* find a parallel in the ovicells of *Lekythopora* and *Pæcilipora*, genera which Mr. P. H. MacGillivray has so well worked out. We notice the same type of mural and peristomial tubules, the same deep-seated opercula and varied zoœcial form. At the same time, it is not possible to escape conviction as to there being two forms of ovicell: the supra-oral type, which is a budding of minute cells at the back of the zoœcium; and the ovicell-sac, which is either inter-zoœcial or borne upon the zoœcial wall. The analogy of the cistern-cell of my Liassic genus *Cisternifera* to the ovicell-sac is apparent, and in one instance there appear to be the rudiments of a spouted process as in *Cisternifera*. These lead to the 'cellules accessoires' of d'Orbigny and possibly to the 'giant cells' of Busk and others.

No author, so far as I know, has commented upon the functions of the zoœcial tubules of *Lekythopora*, so plainly to be seen in the specimen with which Miss Jelly has kindly supplied me. It has seemed, in the study of my fossils, that they may develop around and above the primary aperture. In the Liassic *Cisternifera* a central tubule is a common feature; in *Pergensia* I have noted it in the species *P. porifera*.

Some cells that I have called zoœcia, with flat poriferous faces, may be the columnar vicarious avicularia of Busk, Waters, and others; but there are points of structure, insufficiently worked out, which make such association doubtful.

The stipe of *Lekythopora* and the mode of growth of the colony around it explain the cylindrical axis of *Pergensia*, and show that its 'colonial' growth was after the same fashion.—November, 1893.]

Pergensia, gen. nov.

Zoarium piriform or cylindrical, with a central axial tube round which the zoœcia grow in spiral or irregularly spiral series. Zoœcia tubular, open or with terminal tubules; ovicells supra-oral. Mural openings, front or back. Ovicell-sacs: globose, nest-like cells enveloping the free ends of zoœcia; irregular swellings of the zoarial wall, or globose cells borne on the zoarial wall.

Pergensia nidulata, sp. nov. (Pl. II. figs. 1, 2; Pl. III. figs. 1, 2, 3, 4.)

Maximum zoarial length 4·0 mm., zoarial width 1·1 to 0·5 mm.;

zoœcial length 0·5 mm., zoœcial width 0·17 mm.; mouth 0·1 to 0·07 mm.

Zoarium simple, erect, claviform, base narrow (Pl. II. figs. 1, 2).

Zoœcia tubular, often compressed, springing up closely from the central shaft, frequently with very long exsert ends, of varying form. (1) Pl. III. fig. 1, mouth ovoid, pore on the lower lip, front mural pore; the ovicell is a dome-shaped mass of tubules, with a larger central tubule projecting from the back of the zoœcium: (2) Pl. III. fig. 2, mouth ovoid, quadrate mural pore at the back, apertural plate with a large, transverse, ovoid opening above, tubules and a narrow, transverse opening below: (3) Pl. III. fig. 4, compressed, ending in two compressed tubular shafts or rostra with a narrow opening below: (4) Pl. III. fig. 3, young, two terminal processes, a median ovoid opening, lower labial pore.

Ovicell-sacs globose, nest-like in the free ends of the zoœcia, enveloping two or three; punctulate, like the zoarial surface, with finer pores between them (Pl. II. fig. 1).

The zoœcia tend to a linear arrangement, as in d'Orbigny's genus *Radiotubigera*.

The longitudinal section (Pl. II. fig. 2) shows an axial tube of uniform diameter with thick walls, the primary zoœcia lying close to the tube before trending outward. Stem sinuous.

The shafts or rostra of No. 3 resemble the rostra of the Celleporidæ. In other species of *Pergensia* the rostrum on one side bears an avicularium, while on the other side it bears tubules.

Pergensia major, sp. nov. (Pl. II. figs. 3, 4; Pl. III. figs. 11–18.)

Zoarial length 3 to 4 mm., zoarial width 1 to 3 mm.; zoœcial width 0·3 mm.; mouth 0·1 to 0·13 mm.

Zoarium erect, piriform, base narrow. Zoœcia tubular, springing at regular intervals from the stem outwards; exsert parts of exceptional length (1 mm.). See Pl. II. fig. 4.

Zoœcia: (1) Pl. III. figs. 17, 18, terminal, with a recessed trifoliate or sub-crescentic aperture, supra-oral pore and ovicell-tubules; peristomial aperture hexagonal, with thick raised border: (2) Pl. III. figs. 14–16, zoœcia lengthened, front wall notched or areolated, supra-oral ovicell-tubules, mouth-plate with several openings: (3) Pl. III. figs. 11–13, mouth with terminal tubules and transverse labial opening.

Ovicell-sacs: ovoid, urn-shaped, or irregular. The common form is ovoid, with tubular termination as in *Crisia*. Zoarial surface covered with the protruding ends of pore-tubes, between which are finer pores.

The apertural plate is often pierced with pores, as in Busk's genus *Calymnophora*. Zoœcial covers are scattered sparsely about the zoarial surface.

Pergensia minima, sp. nov. (Pl. II. fig. 12; Pl. III. figs. 5–10.)

Zoarial length 2·0 mm., zoarial width 1·0 mm.; zoœcial length 0·33 mm., zoœcial width 0·13 mm.; mouth 0·07 mm.

Zoarium erect, piriform, beginning with a thin cylindrical stem

bearing few zoœcia, then suddenly increasing in size by rapid multiplication of zoœcia, until a stoutly piriform head of crowded tubes is formed (Pl. II. fig. 12).

Zoœcia small, slightly exsert, tubular, wrinkled: (1) Pl. III. figs. 5–8, with ovoid mouth, supra-oral ovicell proceeding from the back, pore below the lower lip: (2) compressed, mouth ovately triangular, two short processes above, trifoliate opening at the back: (3) Pl. III. fig. 10, mouth ovoid, lip arched, apertural plate with a transverse ovoid opening and tubules.

The ovicell-sacs are globose swellings enveloping several zoœcia. Pl. III. fig. 8 may represent an early stage of one. It bears a flat top with a perforated disc.

Pergensia porifera, sp. nov. (Pl. II. fig. 6; Pl. IV. figs. 1–5, 16, 17.)

Zoarial length 3·2 mm., zoarial width 1·0 mm.; zoœcial length 1·4 mm., zoœcial width 0·17 mm.; mouth 0·1 mm.

Zoarium erect, claviform, the axial shaft protruding from the top (Pl. II. fig. 6). Zoœcia arranged in an irregularly linear series, about six to every annulation, tubular, tapering slightly, exsert for one third of the length.

Zoœcia: (1) Pl. IV. fig. 3, central tubular opening, process on each side of the supra-oral rostrum, globular process on the lower lip, mural pore below it: (2) Pl. IV. figs. 1, 2, compressed, upper and lower lip arched, lower lip with pore below, ovicell supra-oral, springing from the back of the zoœcium: (3) Pl. IV. fig. 17, young zoœcium at the top of the zoarium, with ovoid mouth, trifoliate aperture, and pores around it on the inner wall; small avicularia on the lower lip: (4) mural pore orbicular, with cover (Pl. IV. fig. 5).

Zoarial surface punctate, with fine intermediate pores.

One of the doubtful zoœcial forms, resembling a columnar avicularium (Pl. IV. fig. 16), appears to have a cover, through which the tubules below can be seen.

Pergensia porifera is closely related to *P. nidulata*, but as yet the ovicell-sacs have not been found.

Pergensia amphoralis, sp. nov. (Pl. II. fig. 8; Pl. III. figs. 21–24.)

Zoarial length 4·0 mm., zoarial width 1·0 mm.; mouth 0·07 mm.

Zoarium erect, claviform to cylindrical, axial tube protruding at the base and summit (Pl. II. fig. 8). Zoœcia sub-immersed, or free for half their length, crowded, equidistant, arranged in vertical lines or irregular, about sixteen to a volution.

Zoœcia: (1) Pl. III. fig. 21, upper lip arched, ovicell at the back, aperture ovoid, recessed: (2) Pl. III. fig. 24, compressed, front lip notched, or the wall areolated; mouth ovoid, with tubules. Front mural pore.

Zoœcial coverings, pitted with the impress of tubules, occur detached on the zoarial surface. Clusters of tubuli are to be seen between the zoœcia in one or two specimens. The ovicell-sacs have not been found.

Var. *a*.—Pl. II. fig. 5.

Young, amphora-shaped.

Zoœcia: upper lip arched, with pore, recessed ovoid aperture, lower labial pore, short side-processes, sessile mural avicularium. Ovicell supra-oral, proceeding from the back of the zoœcium. Ovicell-sacs not known. Upon the front wall of certain zoœcia is traced a large scar.

PERGENSIA JUGATA, sp. nov. (Pl. II. figs. 9, 10; Pl. IV. figs. 6–13, 18–21.)

Zoarial length 5·0 mm., zoarial width 1·0 mm.; zoœcial width 0·12 to 0·15 mm.; mouth 0·06 mm.

Zoarium dumb-bell shaped, axial tube protruding at each end. Zoœcia diverging from the constricted central part in apparently linear series or in spiral, often irregular lines (Pl. II. figs. 9, 10).

Zoœcia tubular, tapering, or compressed, some placed sideways upon the zoarium, frequently with long exsert parts: (1) Pl. IV. figs. 7, 10, 11, conoidal, compressed, placed sideways upon the zoarium, front having a long transverse opening below and other openings above, with tubules; summit open, with tubules: (2) Pl. IV. fig. 12, compressed, mouth ovoid, with lobed superior and ovoid inferior openings; ovicell at the back: (3) Pl. IV. fig. 9, mouth ovately triangular; upper lip arched, with pore, lower lip straight, with pore. Clusters of tubuli occur between the zoœcia (Pl. IV. fig. 6).

Ovicell-sacs (Pl. IV. figs. 8, 20) common, inflations of the zoarial surface or cells, enveloping several zoœcia, generally globose: upper surface often flat, the whole pierced and slashed with zoœcial and other openings.

Zoarial surface punctate with protruding pores, wrinkled where the zoœcia are few, the whole covered by an outer film pierced with fine pores.

The longitudinal section (Pl. II. fig. 10) illustrates the divergent growth of the zoœcia from the central part and around the axial tube. In the piriform central cell at the base are numerous reddish-brown, globular, crystalline bodies (Pl. IV. fig. 19). The axial tube also contains some reddish-brown crystals. Sections cut partly through and viewed as opaque objects are great aids in zoœcial study, and illustrate well the mode of growth (Pl. IV. fig. 21). Some details can often be seen by staining the specimen.

PERGENSIA JUGATA, var. BI-GIBBOSA, nov. (Pl. II. fig. 11; Pl. IV. figs. 14, 15.)

Same form as *P. jugata*, with slightly stouter zoœcia. Primary aperture coarctate (Pl. IV. fig. 14) with ovoid peristomial aperture; avicularium on the side of the zoœcium: ovicell-sacs cordate, or in the form of irregular cells or swellings (Pl. IV. fig. 15).

PERGENSIA GALEATA, sp. nov. (Pl. III. figs. 19, 20, 25–33.)

Zoarial width 1·3 mm.; zoœcial length 1·0 mm., zoœcial width 0·1 mm.; mouth 0·09 mm.

Zoarium erect, cylindrical, of nearly equal thickness throughout. Zoœcia tubular, obscurely arranged in a linear series, often compressed, exsert for one half or more of their length (Pl. III. fig. 27).

Zoœcia: (1) Pl. III. fig. 33, upper lip arched, aperture coarctate, peristomial aperture ovately triangular, thick; ovicell supra-oral, front mural pore triangular: (2) Pl. III. fig. 30, compressed, mouth filled with tubules, front wall having a furrow and a narrow ovoid opening; at the base an oval opening with very fine tubules (? ovicell): (3) Pl. III. figs. 25, 26, compressed, with two terminal rostra—one with tubules, the other with a narrow opening, a small opening at the junction of the rostra, an ovicell-sac or opening at the base, as in *Lekythopora hystrix*, MacGil.

Zoœcial covers (Pl. III. fig. 29) are scattered on the zoarial surface, whether pushed off at a certain stage of development, or sheared off in fossilization, it is hard to say. Surface punctate, with fine inter-pores.

The twin rostral processes spring from above a central opening or aperture, and are similar to the twin rostral processes of *Cellepora hastigera*, Busk.[1]

Summary.

1. The discovery in the Inferior Oolite of the South of England of bryozoa belonging to the Cheilostomata, a sub-order not definitely known below the Cretaceous group.

2. The occurrence in the same colony of bryozoa having the form of ovicell and long tubular zoœcia of the Cyclostomata, together with the appendages and apertures of the Cheilostomata.

3. The description of a new genus *Pergensia*, characterized by a long cylindrical axis, globose ovicell-sacs on the body of the zoarium and supra-oral ovicell, zoœcia with trifoliate opercular aperture or with various openings and tubules.

4. The description of the following species:—

Pergensia nidulata, *P. major*, *P. minima*, *P. porifera*, *P. amphoralis*, *P. jugata*, *P. jugata* var. *bi-gibbosa*, and *P. galeata*.

EXPLANATION OF PLATES II.-IV.

Plate II.

Fig. 1. *Pergensia nidulata*, sp. nov. ×12.
2. " " Longitudinal section, showing the axial tube. ×12.
3. " *major*, sp nov. Longitudinal section, showing the axial tube and ovicell-sac with termination. ×12.
4. " " ×12.
5. " *amphoralis*, sp. nov., var. *a*. ×25.
6. " *porifera*, sp. nov. ×25.
7. " sp. Longitudinal section. ×20.
8. " *amphoralis*, sp. nov. ×12.
9. " *jugata*, sp. nov. ×12.
10. " " Longitudinal section, showing the axial tube and divergent growth of zoœcia. ×12.
11. " " var. *bi-gibbosa*. ×12.
12. " *minima*, sp. nov. ×12.

[1] By Mr. R. Kirkpatrick's courtesy I was enabled to examine Busk's types in the British Museum (Natural History), at South Kensington.

Plate III.

All the figures in this Plate are magnified 50 diameters, except fig. 27, which is ×12.

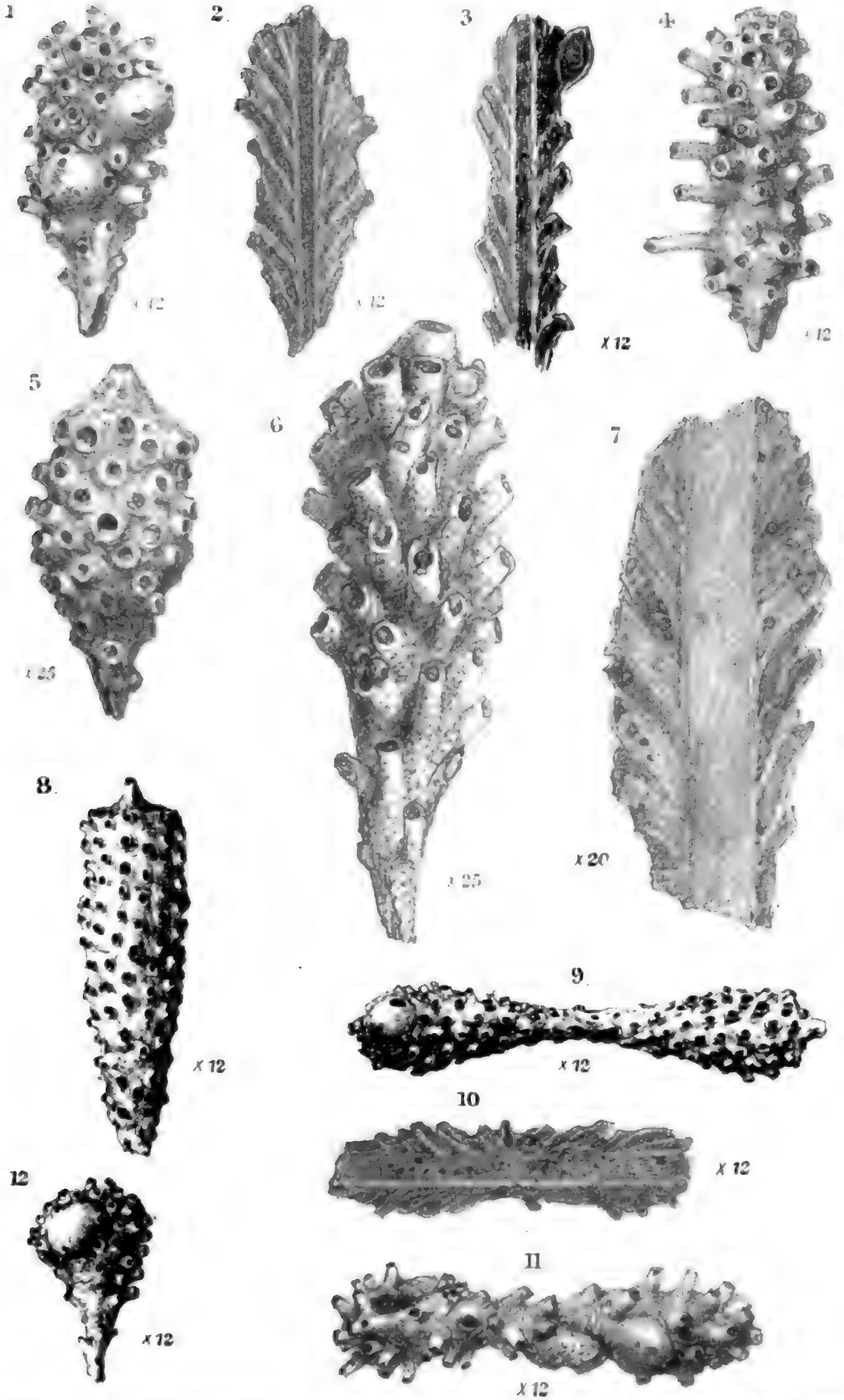
Fig. 1. Zoœcium of *Pergensia nidulata*, sp. nov. with supra-oral ovicell.
2. " " " with apertural plate.
3. " " " young.
4. " " " with rostral processes, broken.
5. " *Pergensia minima*, sp. nov.
6. " " " with supra-oral ovicell.
7, 8, 9. Zoœcia of " " 7 and 8 viewed from different points.
10. Zoœcium of " " with apertural plate.
11, 12, 13. Zoœcia of *Pergensia major*, sp. nov. 12 and 13: the same zoœcium viewed from different points.
14. Zoœcium of " " with notched lip.
15. " " " with mural opening at the back.
16. " " "
17, 18. Apertures of " "
19. Zoœcium of *Pergensia galeata*, sp. nov.
20. " " " with tubules.
21, 22, 23, 24. Zoœcia of *Pergensia amphoralis*, sp. nov.
27. *Pergensia galeata*. sp. nov.
25. Zoœcium of *Pergensia galeata*, with rostral processes and opening.
26. " " " like fig. 25, but with basal (ovicell?) opening.
29. " " " with termination displaced.
28, 30, 31, 32. Zoœcia of *Pergensia galeata*.
33. Zoœcium of *Pergensia galeata*, with mural pore.

Plate IV.

Figs. 1, 2. Zoœcia of *Pergensia porifera*, sp. nov. ×50.
3. " " " with broken mouth. ×50.
4. Zoœcium of " " with mural pore. ×50.
5. " " " with mural pore and cover. ×50.
6. Zoœcia of *Pergensia jugata*, sp. nov. with clusters of interzoœcial tubules. ×50.
7. Zoœcium of " " " terminal tubules & mural openings. ×50.
8. Ovicell-sac of " " ×50.
9–13. Zoœcia of " " ×50.
14. Ovicell-sac of *Pergensia jugata*, var. *bi-gibbosa*, nov. ×50.
15. Zoœcium of " " " " ×50.
16. Avicularium(?) of *Pergensia porifera*. ×50.
17. Zoœcium of " " ×50.
18. *Pergensia jugata*. End of zoarium, showing the compressed termination of the axial tube. ×25.
19. " " Longitudinal section, showing globose crystalline bodies in the cell and the axial tube. ×100.
20. " " Ovicell-sac. ×50.
21. " " Longitudinal section, partly cut through and viewed as an opaque object, to show the cell-arrangement above the axial tube. ×15.

Discussion.

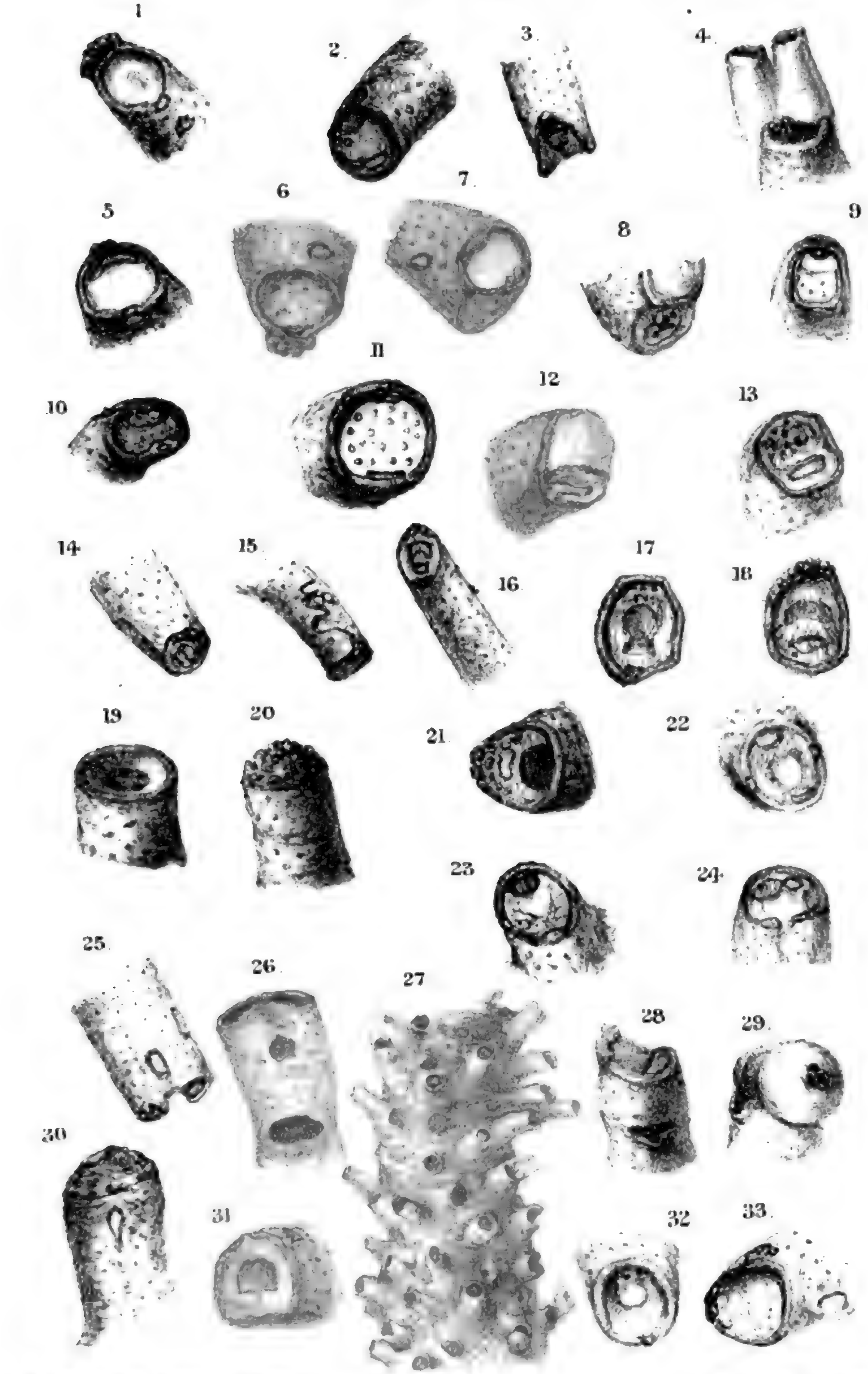
The President said that this was a paper which could be appreciated only after it was printed. Great interest attached to it, because the Author described a genus which blends together two sub-orders.



E. A. Walford del. F. H. Michael lith.

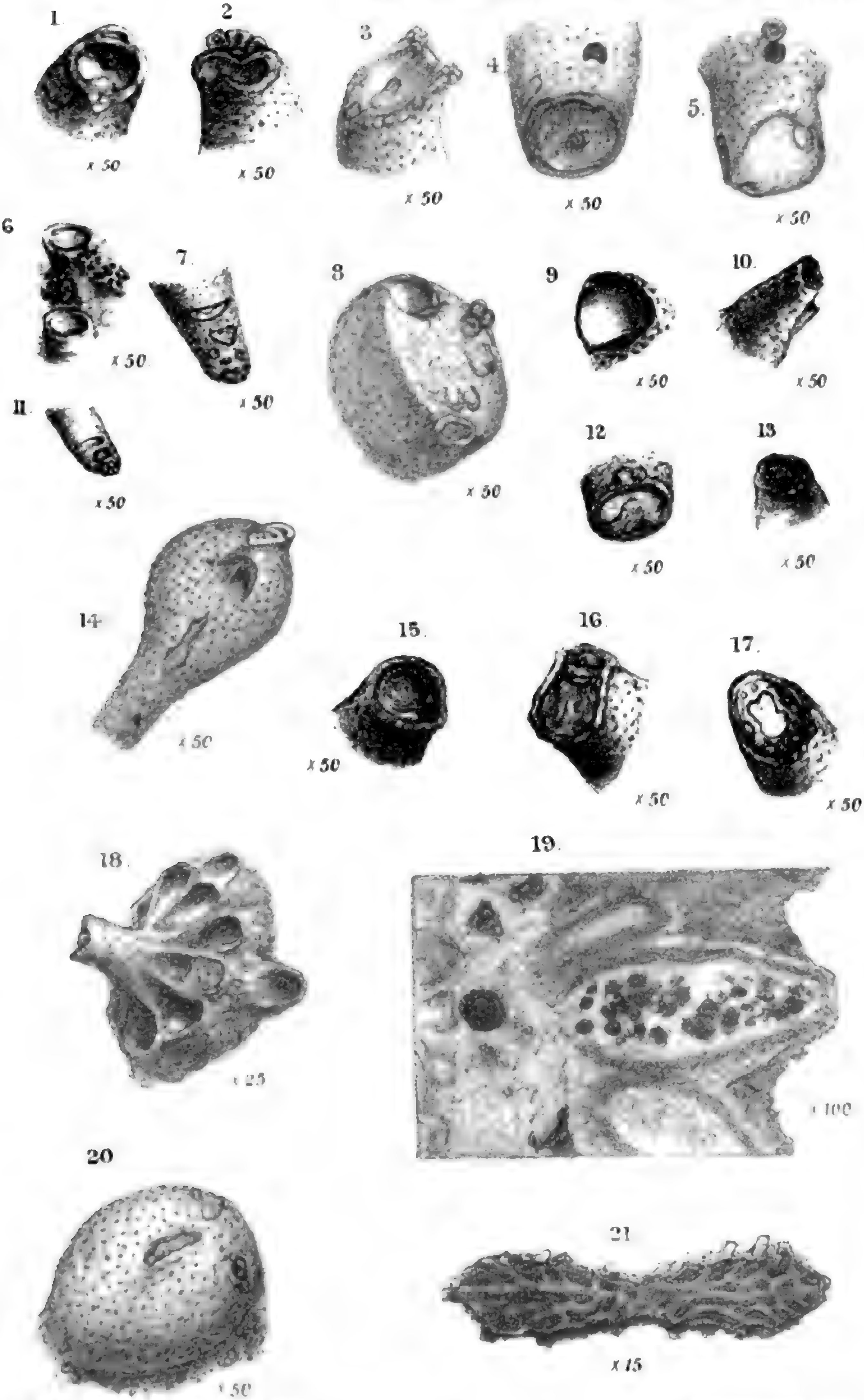
Mintern Bros. imp.

INFERIOR OOLITE BRYOZOA.



E. A Walford del. F. H. Michael lith. Mintern Bros. imp.

INFERIOR OOLITE BRYOZOA.



E. A. Walford del. F. H. Michael lith. Mintern Bros. imp.

INFERIOR OOLITE BRYOZOA.

7. *On* Cheilostomatous Bryozoa *from the* Middle Lias.

By Edwin A. Walford, Esq., F.G.S. (Read June 21st, 1893.)

[Plates V.–VII.]

I described in 1887, in my 'Notes on some Polyzoa from the Lias,'[1] what then appeared to be a well-marked cyclostomatous form of bryozoa under the name of *Tubulipora inconstans*. Since then, I have detected and have recently made known the presence of cheilostomatous species in the Inferior Oolite, and after long periods of search I have acquired more perfect specimens of the Middle Lias bryozoa. The exquisite preservation of these Liassic fragments enables me, without doubt, to carry back the presence of the sub-order another stage in geological time, and to add another link towards the better understanding of the doubtful forms of the Palæozoic rocks.

At first I was inclined to associate the species with d'Orbigny's genus *Elea*; but the long tubular zoœcia, the orbicular as well as the apparently triangular apertures, the ovoid opercula, and the cistern-shaped cells show that the species must be placed elsewhere. Nor does the modern reading of the genus *Lepralia* allow of the inclusion of these forms, though there are points of relationship. Hence it becomes necessary to add a new genus to an already over-burdened nomenclature: for this, then, I select the name *Cisternifera*, from the shape of certain giant cells found thereon. Their relationship to the cyclostomatous ovicell is probable. Furthermore, in some of the so-called *Diastopora* in my collection from the Great Oolite of Oxfordshire I have detected similar ovicells (Pl. V. figs. 14 and 15), and I should say that those of *Berenicea Archiaci*, Haime, are undeveloped forms of kindred cells. That author, in his excellent monograph, writes:—"Des masses calcaires, trois ou quatre fois plus grosses que les testules, lisses et de forme ovalaire, sont éparses à la surface entre les testules et dans la même direction que celles-ci. Ce sont vraisemblablement les restes des capsules ovariennes."[2] His species came from the Inferior Oolite of Longwy and Plappeville-les-Metz. There can be no doubt that a considerable section of such diastoporidian forms will need to be transferred to the Cheilostomata, but not until long-continued search shall have yielded really good enough specimens.

All the forms described are from the marlstone rock-bed of the Middle Lias (zone of *Ammonites spinatus*), King's Sutton, Northamptonshire, and are in my own collection. Specimens of the type-form were also found in Mr. W. Lovell's quarry, when the stone was quarried for iron ore, by Mr. Innes Griffin, F.R.C.S. The excellence of preservation is due to the material having been enclosed in

[1] Quart. Journ. Geol. Soc. vol. xliii. pp. 632–636, pl. xxv.

[2] 'Descr. des Bryoz. Foss. de la Form. jurass.,' Mém. Géol. Soc. France, sér. 2, vol. v. (1854) p. 180, pl. iv. fig. 11.

concentric layers of dense ironstone, an evidence also of the early segregation of the iron. Equally well-preserved fossils have been occasionally found, the most remarkable being the leucoid sponge, with its delicate network of spicules, *Leucandra Walfordi*, described by Dr. G. J. Hinde (Ann. & Mag. Nat. Hist. ser. 6, vol. iv. 1889, pp. 352–357 & pl. xvii.).

CISTERNIFERA, gen. nov.

Zoarium foliaceous and bilaminate, or erect, ramose, and cylindrical. Zoœcia long, tubular. Aperture ovoid. Ovicell supra-oral. Giant cistern-cells in the zoarium.

CISTERNIFERA INCONSTANS, Walford. (See Quart. Journ. Geol. Soc. vol. xliii. 1887, pp. 633–634, pl. xxv.) (Pl. V. figs. 1–8, 16, 17.)

Zoarium erect, foliaceous, bilaminate, with flattened or cylindrical branches; or unilaminate and irregular.

Zoœcia radiating fan-like from the base, tubular, lengthened, with proximal ends free.

Secondary aperture orbicular or ovoid; tube thin, often lengthened.

Apertural plate, with central infundibuliform opening, clithridiate in the early stage; ovicell-tube opening at the superior border, ovoid operculum at the lower border (Pl. V. fig. 1). The plate is pitted here and there, and frequently bears raised openings on the right and left of the central opening. Upper lip of certain zoœcia arched, bearing an avicularian cell (Pl. V. fig. 2). The ovicell-tube passes through the back of the zoœcium, and communicates with a hyaline ovicell, faint traces of which are seen on the walls of the zoœcium above (Pl. V. figs. 3, 6). One or two pores below the lower lip (Pl. V. fig. 1).

In another specimen, from which figs. 5 and 8 are taken, the infundibuliform opening varies from the centre to the lower part of the plate, and communicates apparently with a tubule, as in the latter figure.

Cistern-cells not found as yet on this form.

The zoœcia are separated by raised violet-coloured margins, and bear numerous serried folds down the centre.

CISTERNIFERA INCONSTANS, FORMA PRIMA. (Pl. V. figs. 9–13.)

Zoarium erect, foliaceous, bilaminate. Zoœcia lengthened, tubular, radiating from the base, with long, free proximal ends.

(1). With an acute and slightly arched upper lip, bearing an avicularian cell. Apertural plate, with a central infundibuliform opening and an ovicell-tube opening.

(2). Apertural plate, with an ovoid opercular aperture near the lower lip, two small central perforations, and an ovicell-tube opening. Peristome raised, thin (Pl. V. fig. 9).

(3). Aperture ovoid, with an erect or arched rostrum proceeding from the back, bearing a pore at the apex. Mouth divided into two

unequal parts, the upper section fronted with tubuli, the lower and larger section closed by a flat plate pierced with few pores, small opening at the base. (Pl. V. fig. 17.)

Central and other tubuli are shown in worn cells (Pl. V. fig. 12).

Small avicularium upon the front wall.

Cistern-cell (Pl. V. figs. 10, 11) about three times as long and broad as the ordinary zoœcia, with a broad spout-like process opening into a thick-lipped, transversely ovoid, basin-shaped recess. The whole resembles a spouted upright cistern in the zoarium. The spout-like process is sometimes above, but more generally below the border of the basin into which it looks. Surface covered with pore-tubes like the zoœcia.

Zoœcial margin of a dark purple colour, sometimes raised. Zoarial surface covered with fine pore-tubes and minute spines.

In *Lepralia* (?) *syringopora*, Reuss, Mr. Waters[1] describes some 'closures' over the aperture having a tubule in the centre similar to those of many *Diastoporæ*. It appears to be related to the infundibuliform opening in my *Cisternifera*. There are pores on each side of the central opening in *Cisternifera*, and pores on each side of the centre of the aperture in *L. syringopora*. A transverse oral bar occurs in other forms. Busk figures an infundibuliform cup in his *Chorizopora honolulensis*,[2] but gives the primary orifice as its origin.

CISTERNIFERA INCONSTANS, FORMA SECUNDA. (Pl. VI. figs. 14–22.)

Zoarium erect, foliaceous, bilaminate. Zoœcia lengthened, tubular, spreading fan-like from the base, proximal ends free for one-third of the length.

Secondary aperture orbicular, ovoid or shovel-shaped. In the latter the upper lip is raised, thin, squared, and bears two pores (Pl. VI. figs. 15, 16, 21).

(1). Apertural plate with central opening and pores, and ovoid opercular aperture at the lower lip (Pl. VI. fig. 14). Apertural plate of shovel-shaped zoœcia variously pierced (Pl. VI. figs. 15, 16).

(2). Apertural plate with sub-central, oblong aperture and ovicell-pores. (Pl. VI. fig. 22.)

(3). Apertural plate with sub-central, oval aperture and ovicell-tube opening. Ovicell proceeding from the back of the cell, and traced on the zoœcial wall at the rear. (Pl. VI. fig. 17.)

The cistern-cell is thrice as long and broad as the zoœcia, and has at the top a broad, spout-like process, opening into a transversely ovoid, basin-shaped recess. It is punctulate: the ordinary zoarial surface is covered with larger pore-tubes.

The zoœcia appear to be multiform, apart from the accidents of fossilization, which make even such good material hard to understand. Some have both upper and lower lips produced. The upper lip of the shovel-shaped zoœcium extends until the apertural plate

[1] 'North Italian Bryozoa,' Quart. Journ. Geol. Soc. vol. xlvii. (1891) pp. 20, 21.
[2] Busk, Report on the Polyzoa, 'Challenger' Reports, vol. x. (1884) p. 149.

becomes deeply recessed, and the lip ultimately bears a large, quadrate recess (ovicellular).

An infundibuliform opening occurs in the apertural plate of certain zoœcia (Pl. VI. fig. 14). The plate is pore-pierced, and its lower part and the adjoining part of the lower lip often (where it is very thin) are broken away, leaving an irregular triangular opening.

Mouth often divided by a transverse bar. (Pl. VI. fig. 22.)

Cisternifera inconstans, forma tertia. (Pl. V. figs. 18–21; Pl. VI. figs. 1–4.)

Zoarium foliaceous, bilaminate. Zoœcia lengthened, tubular, proximal ends free for nearly one-half of the length.

Apertural plate with ovicell-tube opening and ovoid opercular aperture near the lower lip, which is sometimes indented. (Pl. V. fig. 18.)

Upper lip arched and lengthened, with ovicell-tube, or ending in a thin, squared, vertical, plate-like process pierced with two pores (Pl. VI. fig. 1). Ovicell-tube passing through the back and communicating with part of an ovicell traced on the wall of the zoœcium above (Pl. VI. fig. 1). A mitre-shaped ovicell with a pore at the summit is figured (Pl. VI. fig. 4).

At the top of the zoarium one of the immature zoœcia has the upper part covered with a perforated curtain, analogous to the perforated front of the form figured in Pl. VI. fig. 3.

Cisternifera inconstans, forma quarta. (Pl. VI. figs. 5–13.)

Zoarium encrusting. Zoœcia spreading fan-like from the base, and looking towards the upper zoarial surface: tubular, and with proximal ends free for nearly one-half of the length, marginal zoœcia nearly immersed.

Zoœcia with lip arched above an ovicell-tube; centrally a pore-tube rounded or irregularly sub-quadrate, bearing a spherical granular mass pierced with fine pores. Aperture ovoid, with a plain ovoid operculum near the lower lip. (Pl. VI. figs. 5, 6, 7.)

A ribbon-like septal loop occupies the central part of a zoœcium and makes an irregular cell or cup in the mouth (Pl. VI. figs. 9, 12). It seems to be a further development of the central tube.

Worn cells show a central tubule, the base of the central tube.

Cisternifera clausa, sp. nov. (Pl. VII. figs. 1–11.)

Zoarium erect, ramose, branches cylindrical or flattened. Zoœcia lengthened, tubular, with free proximal ends.

Aperture orbicular or ovoid, peristome elevated.

(1). Apertural plate with ovoid ovicell-opening and oblong opercular aperture at the lower border, the intervening area with tubuli. (Pl. VII. figs. 2, 3, 4, 9.)

(2). Apertural plate pierced with tubuli in the upper part, with an oblong ovoid opercular aperture at the lower border. Ovicell-tube springing out of the back of the zoœcium, certain zoœcia ending in a triangular apex with a pore at the summit. (Pl. VII. fig. 5.)

Traces of an erect, hyaline, globose ovicell are present rarely on the wall of the zoœcium above. (Pl. VII. fig. 6.)

Cistern-cell about thrice the length and breadth of the common zoœcia, occupying their place in the zoarium, vertical, ending in a broad, spout-like process, without recess or lower opening. (Pl. VII. fig. 7.) Surface covered with the protruding ends of surface-pores like the zoarium.

[Further study has enabled me to discover a primary plate, pierced with one opening of varying shape, or with several segments. It is deep-seated, and the termination or sub-termination of the zoœcial tube is closed with the apertural plate. Presumably from the primary plate arises the central tubule, on the upper side of which are the various tubes and septal divisions making up and leading to the inner part of the ovicell (one sees the outer or supra-oral part of the ovicell traced on the zoœcial wall). Below the central tubule is what I take to be the true zoœcial tube which opens within the mouth. Apparently it turns outwards with the closing up of the mouth by the mouth-plate with the infundibuliform opening, and merges into and becomes a labial aperture. A scutum (or lip-pore) is traced on the under lip, but it and the connected part of the apertural plate are generally broken away; see Pl. VII. figs. 13, 14. The spherical bodies borne on the tubule of *forma quarta* appear to be reproductive. I have been greatly aided by the study of specimens such as *Liripora*, of P. H. MacGillivray, kindly given to me by Miss E. C. Jelly, whom few surpass in knowledge of bryozoa. The study of the Australian forms which Mr. P. H. MacGillivray has worked out so well is a clue to the study of the Jurassic types, for the bryozoan fauna, like the general Jurassic fauna, finds kindred forms in Australian seas.—January 24th, 1894.]

In a Diastoporidian form from the Inferior Oolite (Pea Grit) of Selsey Hill, given to me by Mr. Charles Upton, of Stonehouse, I have noticed similar giant or cistern-cells.

The beautifully-preserved terminations of the surface-pores are shown in Pl. VII. fig. 15.

In many instances the zoœcia figured are from one zoarium.

EXPLANATION OF PLATES V.–VII.

Plate V.

Fig. 1. *Cisternifera inconstans*, gen. & sp. nov. Zoœcium with infundibuliform opening, aperture, and labial pore. ×60.

2. ” ” Zoœcium with avicularian cell and broken apertural plate. ×60.

3, 6. ” ” Zoœcia with tracery of supra-oral ovicell. ×60.

4, 5, 8. ” ” Zoœcia. ×60.

7. ” ” Top of zoœcium, showing the central tubule. ×60.

9. ” ” *forma prima*. Zoœcium with apertural plate and aperture. ×60.

10, 11. ” ” ” Cistern-cells. ×60.

12. ” ” ” Zoœcium with tubule. ×60.

13. ” ” ” with apertural plate. ×60.

Figs. 14, 15. Zoœcia and cistern-cells of so-called *Diastopora*, from the Great Oolite. ×50.
16, 17. *Cisternifera inconstans.* Zoœcia (?) with apertural plates. ×60.
18. „ „ *forma tertia*, with recessed apertural plate and openings. ×60.
19, 20, 21. „ „ „ Zoœcia. Figs. 19 & 20 with oral bar. ×60.

PLATE VI.

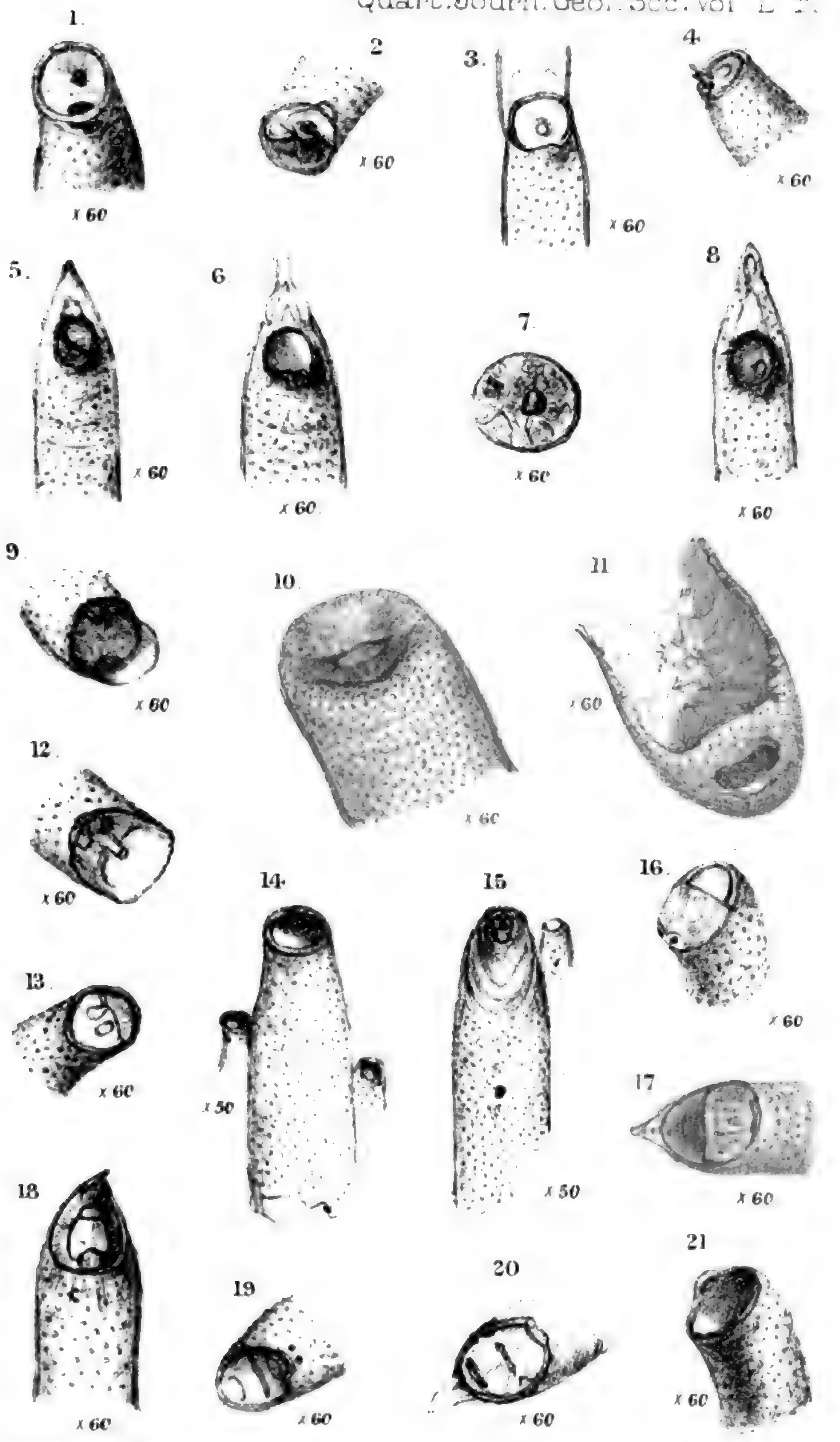
Figs. 1, 4. *Cisternifera inconstans, forma tertia.* Zoœcia with traces of supra-oral ovicell. ×60.
2. „ „ „ Zoœcium. ×60.
3. „ „ „ with perforated curtain over mouth of zoœcium. ×60.
5. *Cisternifera inconstans, forma quarta.* Zoœcium with spherical body covering tubule. ×60.
6, 7. „ „ „ Zoœcia with apertural plates and labial aperture. ×60.
8, 10, 11. „ „ „ Zoœcia. ×60.
9, 12. „ „ „ Zoœcia with tubules developed into loops. ×60.
13. „ „ „ Zoarium. ×25.
14, 18. „ „ *forma secunda.* Zoœcia with apertural plates and labial apertures. ×60.
15, 16, 19, 21. „ „ „ Shovel-shaped zoœcia. ×60.
17. „ „ „ Zoœcium with traces of ovicell. ×60.
20. „ „ „ Zoœcium. ×60.
22. „ „ „ Zoœcium with apertural plate. ×60.

PLATE VII.

Figs. 1, 5, 6. *Cisternifera clausa*, gen. & sp. nov. Zoœcia showing traces of supra-oral ovicell. ×60.
2, 3, 4, 9. „ „ Zoœcia with apertural plate, ovoid aperture. ×60.
7. „ „ Cistern-cell with spout-like opening. ×60.
8. „ „ Zoœcium showing the position of the ovicell-tube from above. ×60.
11. „ „ Zoarium. ×14.
10, 12. „ *inconstans.* Cistern-cells (fig. 10 shows young cell). ×100.
13, 14. „ „ Zoœcia showing labial aperture. ×60.
15. „ „ Showing the terminations of the surface-pores. ×200.
16. „ *inconstans.* ×14.
17. „ *clausa.* ×14.

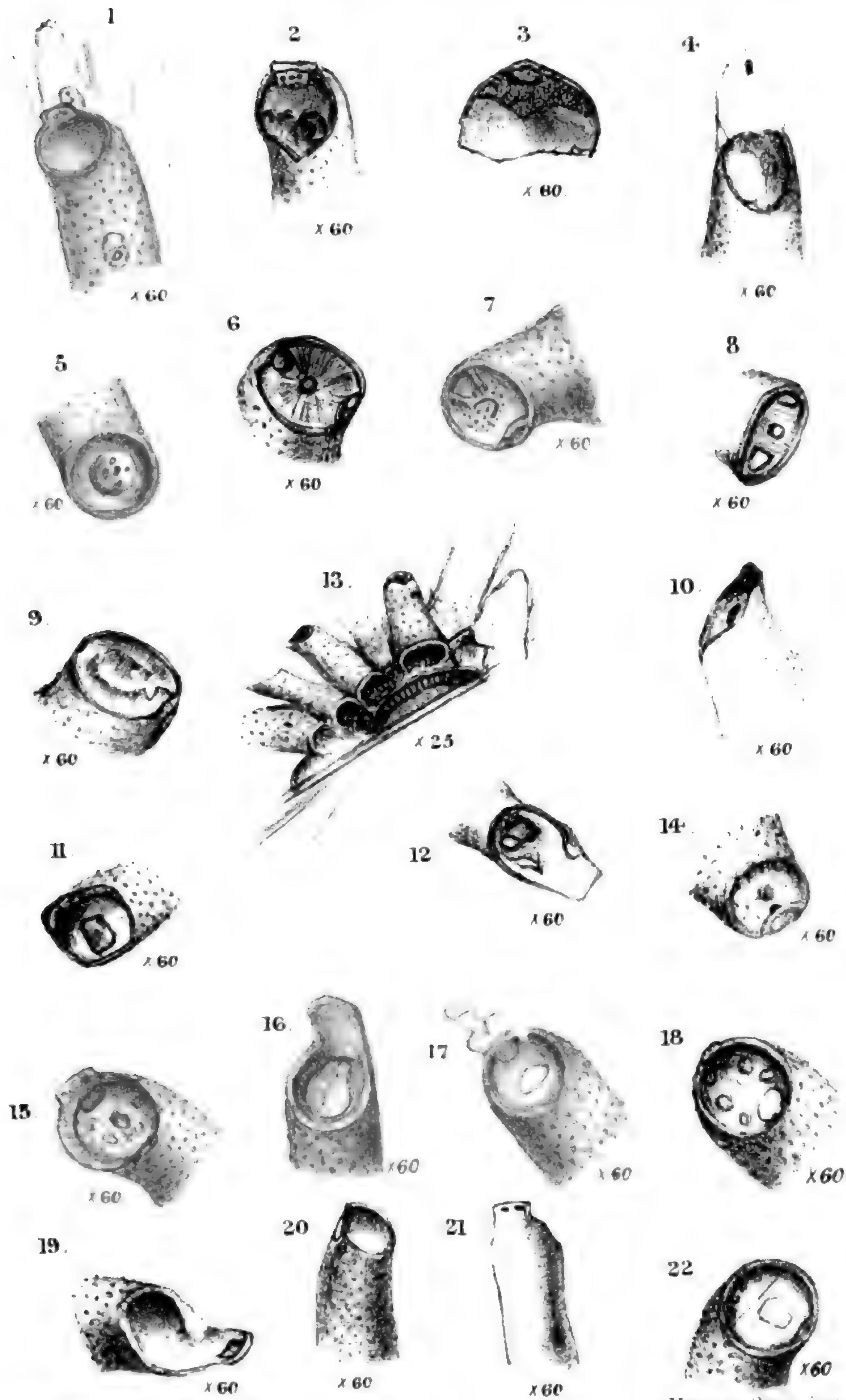
DISCUSSION.

Dr. G. J. HINDE wished to call attention to the remarkably perfect condition of preservation of the delicate bryozoa described by the Author, which appeared to have resulted from their having been enclosed in the interior of ferruginous nodular masses, much in the same way as the fine material in the interior of Chalk flints. In the same material the Author had also discovered some equally perfect, almost microscopic calcisponges, which he (the speaker) had described.



E. A. Walford del. F. H. Michael lith. Mintern Bros. imp.

LIASSIC & OOLITIC BRYOZOA.



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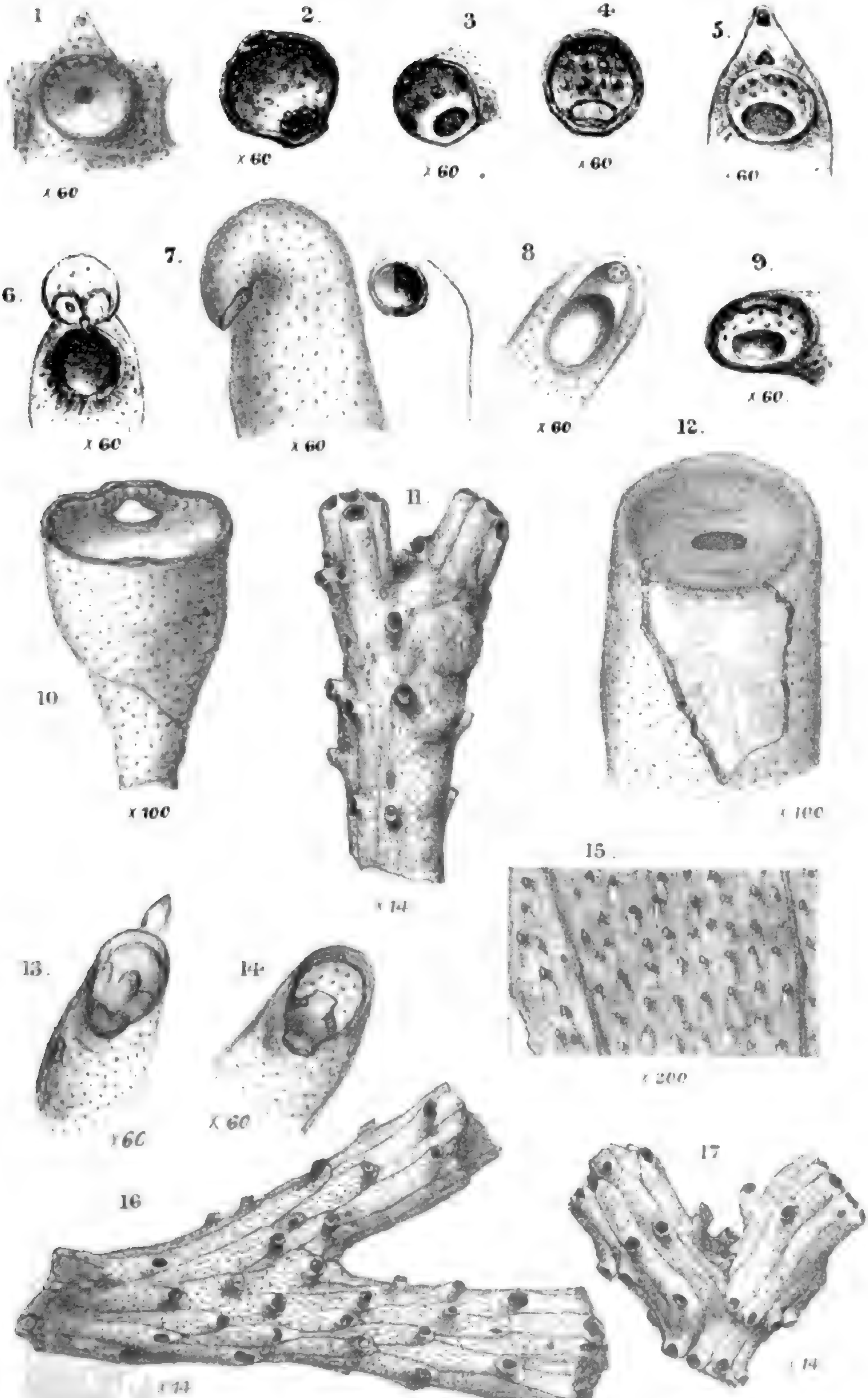
LIASSIC BRYOZOA.



E. A. Walford del. F. H. Michael lith. Mintern Bros. imp.

LIASSIC BRYOZOA.

8. *The* Geology *of* Matto Grosso (*particularly the* Region drained *by the* Upper Paraguay). By J. W. Evans, D.Sc., LL.B., F.G.S. (Read November 8th, 1893.)

[Plate VIII.—Map.]

Contents.

[*Note.*—The italic numerals in parentheses, throughout this paper, refer to the works quoted in the bibliographical list.]

I. Introduction.

I spent some time in this part of South America in the years 1891 and 1892, but unforeseen circumstances seriously interfered with geological work. The present paper is the result of such observations as I was able to make, and I have to thank the other members of the expedition (including the leader, Lieut. O. T. Storm, of the Scandinavian Navy; his brother, Mr. Johan Storm; and Mr. Spencer Moore, the well-known botanist) for doing all that was possible to facilitate my labours.

Very little has hitherto been known geologically of most of the country I traversed. A short account of A. d'Orbigny's valuable work in the adjoining portion of Bolivia in the year 1842 (*1*) is given in the present paper (p. 96). Castelnau visited Matto Grosso in 1843–44 (*2*), Chandless about 1864 (*3*), the Brazilian and Bolivian Joint Boundary Commission in 1875–78 (*5*), and Von den Steinen with Clauss in 1884 and subsequently (*6*) & (*7*); but they have not given us any very definite geological information. Several years ago Mr. Herbert H. Smith resided for about two years in the Chapada near Cuyabá, being engaged in zoological collecting. Some fossils obtained by him were described by Mr. Orville A. Derby in an important paper in which he summarized all that was then known of the geology of Matto Grosso (*8*).

The last-named gentleman has kindly perused this paper, and I have had the benefit of his observations upon it: they have especial value on account of his extensive acquaintance with the geology of other parts of Brazil. I am indebted to Mr. A. M. Davies, F.G.S., for invaluable assistance in seeing this paper through the press, and to Mr. W. Rupert Jones for careful revision of the references throughout, a task which I was unable to undertake myself, on account of my being now resident in India.

The map which accompanies the present paper (Pl. VIII.) shows the routes taken both by Castelnau and by myself, and also the geological structure of the country, so far as I have been able to ascertain it. I have inserted a few details on the authority of Castelnau, but it is not easy to gather the exact nature of the rocks from his descriptions.

II. Bibliography.

a. Publications referred to in this paper in connexion with Matto Grosso or Eastern Bolivia.

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(*2*) Castelnau, Comte Francis de, 'Expédition dans les Parties Centrales de l'Amérique du Sud,' 1ère Partie (Histoire du Voyage), vols. ii. & iii.; 4ème Partie (Itinéraires et Coupes Géologiques); 5ème Partie (Géographie): Paris, 1850–57.

(*3*) Chandless, W., Journ. Roy. Geogr. Soc. 1866.

(*4*) Lloyd, . . . , 'Caminho de ferro d'Isabel, da Provincia do Paraná á [aquella] de Matto Grosso,' Rio de Janeiro, 1875.

(*5*) Fonseca, Dr. João Severiano da, 'Viagem ao redor do Brasil' (two vols.), Rio de Janeiro, 1880.

(*6*) Clauss, Otto, 'Bericht über die Schingú-Expedition im Jahre 1884,' Petermann's Mittheilungen, vol. xxxii. (1886) pp. 129–134, & pp. 162–171. (This gives an account of K. von den Steinen's expedition.)

(*7*) Von den Steinen, Karl, 'Durch Central-Brasilien. Expedition zur Erforschung des Schingú im Jahre 1884,' Leipzig, 1886.

(*8*) Derby, Orville A., 'Nota sobre a Geologia e Paleontologia de Matto Grosso,' Archivos do Museu Nacional do Rio de Janeiro, vol. ix. (1890) pp. 59–88.

b. Publications referred to in this paper, relating to the geology of other parts of South America.

(*9*) Hartt, Charles Frederick, 'Scientific Results of a Journey in Brazil. By Louis Agassiz and his Travelling Companions.—Geology and Physical Geography of Brazil' (Boston, 1870). (J. A. Allen, Notes by, on Country between Chique-Chique and Bahia.)

(*10*) Derby, Orville A., 'A Contribution to the Geology of the Lower Amazonas,' Proc. Am. Phil. Soc. vol. xviii. (1879) pp. 155–178.

(*11*) ——, 'The Geology of the Diamantiferous Region of the Province of Paraná, Brazil,' *ib.* pp. 251–258.

(*12*) ——, 'Modes of Occurrence of the Diamond in Brazil,' Am. Journ. Sci. ser. 3, vol. xxiv. (1882) pp. 34–42.

(*13*) ——, 'Physical Geography and Geology of Brazil.' This appeared in the 'Rio News' (Dec. 5th, 15th, & 24th, 1884), and was republished as a pamphlet. It is an English translation of chaps. iv.–vi. in vol. 1 (A Geographia Physica do Brasil) of 'O Brasil Geographico e Historico,' por J. E. Wappæus (8vo, Rio de Janeiro, 1884).

(*14*) Pöhlmann, Robert, 'Gesteine aus Paraguay,' Neues Jahrb. 1886, vol. i. pp. 244–248.
(*15*) Derby, Orville A., 'On Nepheline-Rocks in Brazil. [Pt. I.] Quart. Journ. Geol. Soc. vol. xliii. (1887) pp. 457–473.
(*16*) ——, 'On the Magnetite-Ore Districts of Jacupiranga and Ipanema, São Paulo, Brazil,' Am. Journ. Sci. ser. 3, vol. xli. (1891) pp. 311–321.
(*17*) ——, 'On Nepheline-Rocks in Brazil.'—Pt. II. Quart. Journ. Geol. Soc. vol. xlvii. (1891) pp. 251–265.

c. Other papers referred to.

(*18*) Barbour, Erwin H., and Joseph Torrey, Junr., 'Notes on the Microscopic Structure of Oolite, with Analyses,' Am. Journ. Sci. ser. 3, vol. xl. (1890) pp. 246–249.
(*19*) Van den Broeck, Ernest, 'Les Cailloux Oolithiques des Graviers Tertiaires des Hauts Plateaux de la Meuse,' Bull. Soc. Belge de Géologie, vol. iii. (1889) pp. 404–410.
(*20*) Whymper, Edward, 'How to use the Aneroid Barometer,' London, 1891.
(*21*) Gregory, J. Walter, 'The Physical Features of the Norfolk Broads,' Natural Science, vol. i. (1892) pp. 347–355.

III. Physical Features of Matto Grosso.

Matto Grosso is the second largest of the Brazilian States. Its area exceeds 2 million square kilometres[1] (about half a million square miles). It is adjacent to Bolivia and Paraguay, and holds as nearly as possible a central position in the South American continent.

The centre of the State is occupied by an undulating tableland, rising in places to more than 800 metres (2600 feet) above sea-level.[2] It extends from the south-west of the State of Goyaz in a west-north-westerly direction to the cataracts of the Rio Madeira, just above its junction with the Rio Madre de Dios. The eastern portion is called the Chapada, a name commonly applied in Brazil to tablelands like this with precipitous sides. Farther west, the steep southern margin is known as the Serra dos Parecis (from the Indian tribe of that name) and the Cordilheira Geral.

On the northern boundary of the plateau we find the head-waters of the Araguaya, Xingú, and Tapajos, which flow northward into the Amazonas. The southern drainage is performed partly by the Guaporé, a tributary of the Madeira (which above the point of confluence is known as the Marmoré), and therefore of the Amazonas, and partly by the numerous tributaries of the Upper Paraguay.

This tableland is believed to sink more or less gradually to the northward into the Amazonian plain, while on the south there is a

[1] The official unit of distance is the kilometre, but the Brazilian league of 6·6 kilometres (4·1 English miles) is often used.

[2] Calculations from the author's aneroid readings near the village of Sant' Anna da Chapada gave a height of 880 metres or 2860 feet; but no doubt some deduction must be made from this estimate, on account of the progressive changes which Mr. Whymper has shown to take place in an aneroid when it is under diminished pressure: see (*20*) p. 58.

sudden descent to a lower, but still hilly region usually less than 300 metres (about 975 feet) above the sea.[1]

Farther south this hilly country is replaced by extensive marshy plains continuous with the lowlands of Bolivia, the Paraguayan Chaco, and the Argentine plains, and extending with but little increase of elevation to the Bolivian tributaries of the Amazonas. From these alluvial tracts rise here and there a number of rock-masses of various dimensions, from the extensive highlands of the Chiquitos to isolated eminences of insignificant proportions.[2] But in the east the high land of the Chapada continues southward and connects with the hills of Paraguay.

The majority of the rocks in Matto Grosso may be tabulated in the following manner. The correlation of strata in different localities must, in the almost entire absence of fossils, depend to a large extent on lithological characters—an unsatisfactory basis, but all that is at present available. I am responsible for the names of Nos. 2 to 5; I have not seen rocks 7 to 9.

QUATERNARY	10.	Alluvial deposits. High-level surface-deposits.
CRETACEOUS?	9.	Sandstones of the Taboleiros.
TRIAS?	8.	Sandstone, with igneous rocks, near Miranda.
CARBONIFEROUS? ...	7.	Shales, with fossil ferns, near Miranda.
DEVONIAN	6.	Chapada Sandstones and Shales.
		(Probable unconformity.)
PRE-DEVONIAN ...... (As yet unfossiliferous and of unknown age.)	5.	Matto Shales.
		(Relations not shown.)
	4.	Rizama Sandstone.
		(Perhaps some unconformity.)
	3.	Corumbá and Arara Limestones.
		(Very marked unconformity.)
	2.	Cuyabá Slates.
		(Strong unconformity.)
	1.	Ancient crystalline rocks.

IV. Pre-Devonian Rocks.

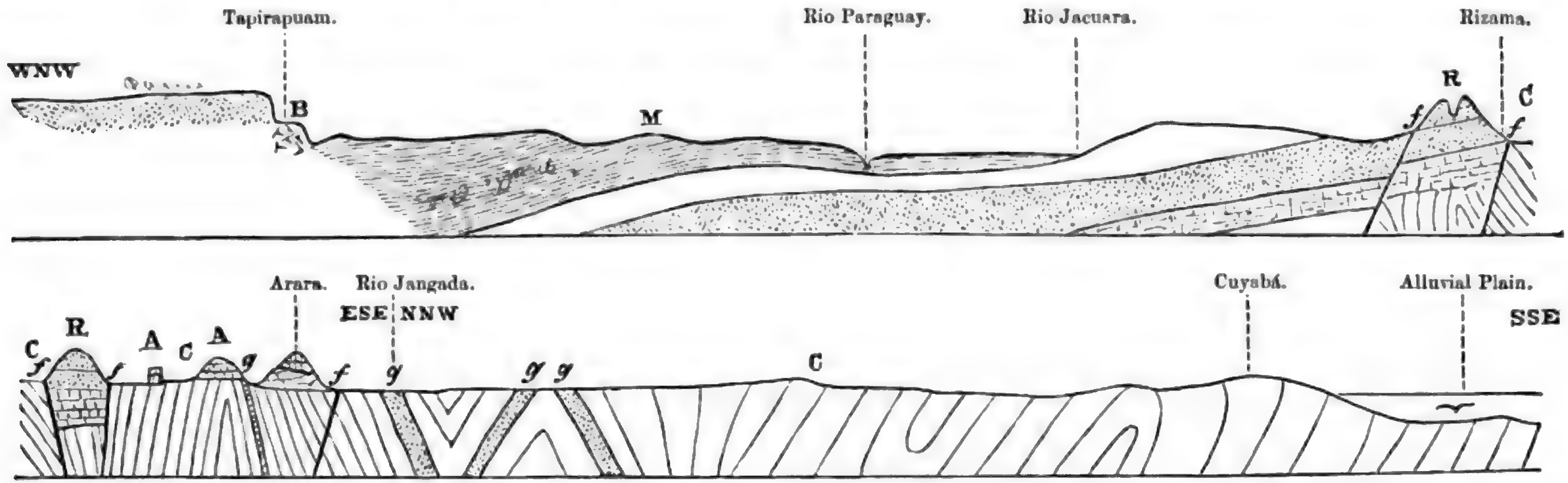
1. Ancient Crystalline Rocks.

These occur *in situ* at Urucúm, near Corumbá. Pebbles of similar rocks are found at various points in the Cuyabá Slates. The Urucúm rocks are foliated and schistose in appearance; though Prof. Bonney, who kindly examined specimens and thin sections of them, thinks that they are really of igneous origin, but have been crushed and sheared so as to take up their present structure. Some

[1] Clauss, from daily barometric readings extending over about two months, calculated the height of Cuyabá as 201 metres or 653 feet, (*6*) p. 168. My aneroid observations, made at Santa Cruz (Barra dos Bugres) on the Rio Paraguay, about 15° S. lat., show the Paraguay there to be a little higher than the Rio Cuyabá at Cuyabá. I found the foot of the Chapada north-west of Cuyabá to be at a height of about 320 metres or 1040 feet above sea-level.

[2] The height of the Paraguay at Corumbá, and therefore practically of the low plain adjoining, appears to be about 120 metres or 400 feet: see (*5*) p. 22.

Fig. 1.—*Generalized Section from the Hills of Tapirapuam to the Alluvial Tract south of Cuyabá.*



B = Basalt.
M = Matto Shales.
R = Rizama Sandstone.

C = Cuyabá Slates (in which g = conglomerate or grit-beds).
A = Arara Limestone.
f = faults.

Note.—Only the general nature of the geological structure and faults is represented. The portion of the section comprised between Rizama and the Rio Paraguay is almost wholly conjectural.

were probably granites originally, others appear to be derived from gabbros or other basic rocks.

At Uacurisal, on the western bank of the Rio Paraguay, a little north of its junction with the São Lourenço, are found some much decomposed crystalline rocks. They are more or less schistose, and consist of quartz-grains often minute, small flakes of white mica, and other white decomposition-products. These rocks are apparently of igneous origin, like those at Urucúm. Farther south, at Dourados, are rocks of a similar character, as well as quartzites.

I nowhere saw undoubted gneisses or crystalline schists. D'Orbigny states that he found them in the Chiquitos in Eastern Bolivia (see *infra*, p. 96). They occur widely in Eastern Brazil.

2. Cuyabá Slates.[1]

These are highly cleaved clay-slates, apparently of great thickness, though the beds are no doubt repeated by folding. They often contain crystals of pyrites, usually very minute.

The slates extend from Cuyabá north-eastward to the foot of the Chapada plateau, where they are covered unconformably by the Chapada Sandstones. In this direction they are much decomposed, being sometimes as soft as clay.[2] They usually dip north-west at 40° to 55°. In some places the stratification can be distinguished from the cleavage, and dips at a lower angle.

North-west of Cuyabá the slates extend across the Rio Cuyabá, and the dip increases till it is vertical, a little south of the Rio Espinheiro. Farther north-north-west the dip becomes south-easterly at a high angle, then it again changes to north-west; but at the Rio Jangada, where the rocks are well shown near the *fazenda* (farm) of Dom Francisco, they dip to the south-east at 50°. Beyond this point I found no exposures till I reached the remarkable series of parallel ridges that run from the Rio Paraguay, near São Luiz de Carceres (Villa Maria), north-east-by-north to the east of Diamantino and west of the upper waters of the Cuyabá.[3] In the longitudinal valleys between these hills the slates are again met with, dipping very steeply, usually north-west or south-east. They underlie unconformably the Arara Limestone.

As I have already remarked (p. 88), the Cuyabá Slates often con-

[1] Similar slates appear to occur in the States of Minas Geraes and Bahia, in the region drained by the rivers Jequitinhonha and Pardo, especially in the Serra de Congonha and Serra do Grão Mogor; also at Calhão, and thence to Minas Novas and the neighbourhood, (9) pp. 138–39, 151–54, 157, 163, 242–43. They usually dip steeply north-west or south-east, as in Matto Grosso, and are said by Hartt to resemble the gold-bearing rocks of Nova Scotia (*op. cit.* p. 157). These slates are also found in Sergipe (*op. cit.* p. 405), Ceará (*op. cit.* p. 464), and in Goyaz near Arrayas (*op. cit.* p. 498); see note, *infra*, p. 91. Similar slates were moreover observed by A. d'Orbigny in the Chiquitos (see *infra*, p. 96).

[2] Hartt met with similar decomposed slates between the Capivary and Minas Novas, *op. supra cit.* p. 154.

[3] The northern portion of these hills is known as the Serra de Tombador and Serra Azul, (2) 5ème Partie, Map 9.

tain pebbles of older rocks. These are of all sizes, up to 8 inches or more across. They are most plentiful in the north-west, and consist mainly of granitoid rocks, in which shear-foliation was already developed before they were included in their present matrix. Some of the pebbles appear to be derived from clastic rocks, and a few may be fragments of a compact lava-like rock. The pebbles are sometimes isolated, sometimes a great number are found together: but each is embedded in the fine-grained matrix of the slate, the divisional planes of which open out, so to speak, and envelop it. In exposures in the channel of the Rio Jangada the slate contains abundant fragments of these materials, which in some places make up one half of the rock. Occasionally (as, for example, about halfway between the Rio Espinheiro and the Rio Jangada) grit-beds of similar materials, but in a finer state of division, occur interstratified in the slate, their outcrops standing out like igneous dykes. Prof. Bonney tells me that specimens of these conglomeratic rocks remind him of some of the ashy beds in the porphyroid of Sharpley, Charnwood.[1]

Castelnau found highly inclined slates with limestone on the Rio Miranda, in South-eastern Matto Grosso; see (*2*), 1ère Partie, vol. ii. p. 466.

3. Corumbá and Arara Limestones.[2]

I have placed these limestones together, though there is no clear evidence that they are of the same age; but there is considerable resemblance between them.

The limestone of Corumbá is well shown in the cliff on which that town stands. It occupies most of the lower portion of the extensive island-like elevation, which at this point diverts eastward the course of the Paraguay.

[1] Slate-conglomerates have been described from the Caxoeirinha do Rio Pardo, Southern Bahia, (*9*) pp. 242–43, and from near Arrayas, Goyaz, *ib.* p. 498. In the latter case the matrix is called by the observer gneiss, but from the description it would appear to be slate.

[2] Limestones of more or less similar character are described as occurring in the valley of the Rio São Francisco, especially on the eastern side. The account given of the limestone of the Rio das Velhas (a tributary of the São Francisco) reminds me of that of Arara, while farther north, near Chique-Chique, the limestone would appear to more resemble that of Corumbá. See (*9*), pp. 278, 310–12, 327–28, 331, and (*12*) p. 35. Similar limestone appears to be found in the basins of the Jequitinhonha and Paraguassú in the States of Minas Geraes and Bahia, (*9*) pp. 138, 302–3; in Goyaz (*op. cit.* p. 497), and also in the Chiquitos (see *infra*, p. 96). I also found a limestone, somewhat like that which occurs at Corumbá, on the eastern bank of the river Paraguay, in the extreme north of the republic of that name.

According to Mr. Derby, "The specimens of limestone that have come to hand from Corumbá are strikingly similar in aspect to the limestones of São Paulo and Paraná that occur in a series that is certainly pre-Devonian, and is presumed to be Cambrian or Lower Silurian. This presumption, however, has for the present no firmer basis than the assumption, as yet unproven, that it is older than a similar but apparently less metamorphosed series in the São Francisco basin in which some obscure fossil corals, apparently of Upper Silurian type, were found by the writer at Bom Jesus da Lapa," (*8*) p. 72.

The limestone is, when purest, dark blue in colour. It passes into paler and more argillaceous beds, and sometimes into a yellowish calcareous shale: it is often siliceous. The dip is usually from 10° to 15° north, but frequently near the margin changes, so as to be directed towards the alluvial plain.

This limestone is also found at low elevations, rising out of the plain north and east of Corumbá, as, for example, at Castelhos and near Carandazinho[1] on the Rio Paraguay.

Behind Corumbá there occurs in the limestone a thick deposit of ferruginous chert. Its superior hardness gives rise to a long ridge at the back of the town some hundred metres high.[2] Near Corumbá the limestone is sometimes brecciated and re-cemented, and I found specimens showing this re-cemented material and also the normal rock silicified into a kind of flint.

At Coimbra is found an impure limestone, often yellowish or red from the presence of iron. Some varieties appear to be dolomitic, as they only effervesce with hot hydrochloric acid. I paid a short visit to a large cavern in this limestone about 5 or 6 kilometres (3 to 3¾ miles) north of Coimbra. It has been often described; see (*2*), 1ère Partie, vol. ii. p. 406, and (*5*) vol. i. pp. 271–285. It has extensive ramifications and numerous stalactites; the floor is generally composed of a ferruginous sand, the residue left after the removal of the carbonate of lime from the limestone.

The Arara Limestone occurs in the parallel ranges of hills already referred to (p. 90) between the upper course of the Paraguay and the Rio Cuyabá, especially at Arara, an isolated hill at the northern end of the most easterly ridge. It is also found in the adjoining range to the westward. South-west of Chapedon, in the valley beyond, is an isolated natural turret of limestone, the rest having been removed by denudation.

This limestone is pale and streaky, rather more compact and altered than that of Corumbá. Close to Arara it usually dips at about 15° to the south-west, but is in some places much contorted. Farther west it is nearly horizontal, while the Cuyabá Slates have a steep dip. As a result of weathering, exposed surfaces of the Arara Limestone become studded with acicular points.[3]

I was unable to find any organic remains in the Corumbá or Arara Limestones; but I was told at São Luiz de Carceres that limestone containing shells is found in the hills east of that town, viz. the southern extension of the hills in which Arara Limestone occurs. It is, of course, possible that these shells are land-mollusca, embedded in travertine of comparatively recent formation.

[1] Near this locality I noticed a large stream flowing into a low cave, at the base of a limestone-hill.

[2] Compare the chert stated to occur in the neighbourhood of Volta da Serra, near Jacobina, in the State of Bahia. It is there called *pedra de fogo* or fire-stone, (*9*) p. 312.

[3] The same effect of weathering has been noted at Chique-Chique; see (*9*) p. 310.

Limestone is also found in the same range of hills north of Arara, near Diamantino, and still farther north; see (*2*), 1ère Partie, vol. ii. p. 302.

The limestone occurring between São Luiz de Carceres and the Registro do Jauru, (*2*) 4ème Partie, pl. 52, may perhaps also belong here.

In the uppermost Paraguay, near Santa Cruz, Barra dos Bugres, I found some curious pebbles of silicified pisolite and oolite, not improbably derived from another exposure of the Arara Limestone. The structure is well shown in thin sections. Hartt found pebbles of an apparently similar rock at Aracaré, a prominent rocky point just below Villa Nova in the State of Sergipe, on the São Francisco, near its mouth, (*9*) pp. 396–97.[1]

4. Rizama Sandstone.[2]

This sandstone overlies the Arara Limestone, to which it is apparently somewhat unconformable. It is an altered and indurated felspathic rock, very different from the Chapada Sandstones, and is well seen in the line of hills (one of the parallel ridges already referred to) which terminates near the little settlement of Rizama, about 55 kilometres or 34 miles (following the bridle-track) east of Santa Cruz, Barra dos Bugres. This range is divided down the centre by a narrow longitudinal valley, which appears to extend for many miles. The same sandstone is found in the adjoining ranges to the east, and also south-west, where one of these parallel ridges abuts on the Rio Paraguay a little above São Luiz de Carceres (see Map, Pl. VIII.).

5. Matto Shales.

These are mainly found west of the uppermost Paraguay, north of its junction with the Rio Sepituba. They appear, however, to occur in the bed of the Rio Jacuara, an eastern tributary of the Paraguay. I could not observe the relations of these shales with

[1] Silicified oolite has also been described from the Assynt Limestone at Stronechrubie, Uamh Valley, Durness; from Centre County, Pennsylvania, (*18*) p. 249; and from the neighbourhood of Namur, Belgium, where pebbles of silicified Jurassic limestone occur in Tertiary deposits, (*19*) p. 404. [I am indebted to Prof. J. W. Judd, F.R.S., for these references, and the opportunity of seeing hand-specimens and thin sections from the localities mentioned.]

[2] I do not know whether the Rizama Sandstone is represented elsewhere in Brazil. Possibly the compact quartzose sandstone, that unconformably overlies the limestone 'at Olhos d' Agua, about seventy-five miles west of Jacobina,' (*9*) p. 311, may correspond to it, and not to the Devonian Sandstone of the Chapadas of Matto Grosso and elsewhere. The Rizama Sandstone certainly appears to occur in the Chiquitos (see *infra*, p. 96). In stratigraphical position it may be compared with a great sheet of sandstone in Northern Minas Geraes and Central Bahia, described by Mr. Orville A. Derby as bent into broad simple folds and lying unconformably on the upturned edges of the Huronian and Laurentian, (*12*) p. 34, (*13*) p. 5; but he tells me that this sandstone does not in any way resemble a specimen of the Rizama Sandstone which I sent him.

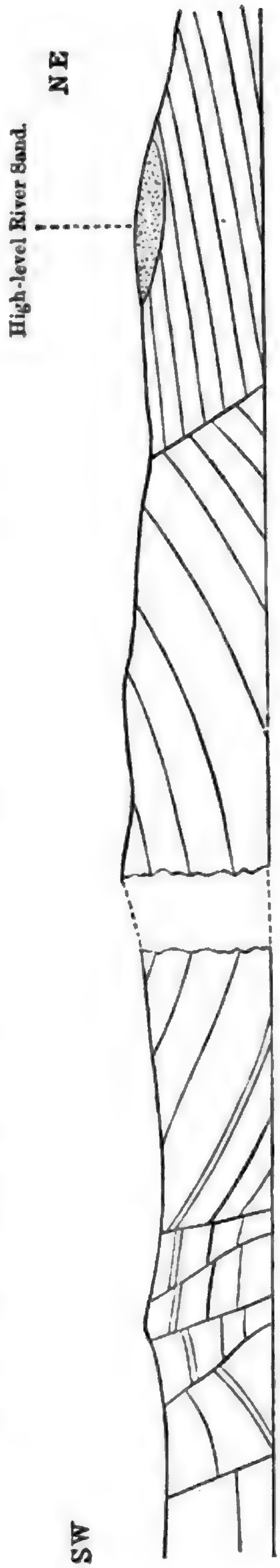


Fig. 2.—Portion of Section on W. bank of Rio Paraguay, about 3½ miles N. of Santa Cruz, Barra dos Bugres.

Length=about 1¼ mile. Height estimated as varying from 25 to 40 feet. The beds shown are the Matto Shales. [The portion omitted in the centre is a wide and gentle synclinal.]

the Rizama Sandstone, because the country between Rizama and the Rio Paraguay is mostly covered by recent deposits and vegetable soil.

None of the rocks previously described in this paper afford very fertile soil: the ground is generally lightly timbered, and the vegetation suffers severely from want of water during the dry season, so that the country has then an almost wintry aspect. The transition to the Matto Shales is marked by the incoming of a continuous forest (*matto*) of lofty trees, beneath whose shade grows the *poaia* (as ipecacuanha is locally called), the roots of which are the principal export from the State. Even towards the end of the dry season these trees preserve their leaves, and many of the streams continue to flow.[1]

The Matto Shales can be well studied in the neighbourhood of the settlement of Santa Cruz, Barra dos Bugres,[2] already referred to. There they undulate in gentle curves, but are repeatedly disturbed by reversed faults. Some of these faults are well shown in the fine section on the right bank of the Paraguay about 6 kilometres or 3¾ miles above Barra dos Bugres (see fig. 2).

The shales are red, with streaks and patches of white. They are comparatively soft, and have a greasy feel. Laminæ of calcite occasionally occur in them.

In travelling up the Paraguay from Barra dos Bugres, exposures

[1] This forest, or an extension of it, appears to furnish the explanation of the name Matto Grosso ('thick forest'), (*5*) vol. ii. p. 1.

[2] Barra dos Bugres means 'the mouth of the Rio dos Bugres,' so called from the Bugres Indians.

of these shales and occasional interstratified grit-beds are seen at intervals. A steady dip of about 15° north-north-west soon sets in, and continues as far as the neighbourhood of Tres Barras.[1] Here the Rio Sant' Anna joins the Paraguay, which has just received the Rio Brumada. I followed the shales for a short distance up the Rio Sant' Anna (where they dipped at 10° north-north-west), and also up the Rio dos Bugres and its tributary the Rio Brazinho. Along the two last-named rivers the shales were more horizontally bedded.

I was informed by reliable Brazilian traders that similar shales are found on the Rio Sepituba, and red argillaceous shales are described by Castelnau as occurring near Diamantino, (*2*) 1ère Partie, vol. ii. p. 323.

I travelled by land about 100 kilometres (or 62 miles) north-west of Barra dos Bugres. No exposure of the shales is met with in the forest, but the nature of the soil and vegetation indicates their continuance till the hills of Tapirapuam are approached. The soil then becomes ferruginous, and the trees smaller and fewer, till a tract of peaty grass-land is reached: beyond this are irregular hills of an olivine-basalt, which weathers into rounded elevations. Behind and above is a line of flat-topped hills, apparently the edge of a sandstone-plateau, which I was unable to visit. Farther north runs a second escarpment, the Serra dos Parecis.

V. Devonian Rocks.

6. Chapada Sandstones.[2]

These sandstones appear to extend over the whole of the great plateau of Matto Grosso, although in some places covered by later beds. They have a slight dip towards the north. On the south, near Cuyabá, they terminate in a lofty escarpment nearly 600 metres (1950 feet) above the undulating slate-plain. The lower half of the escarpment-face consists of a steep slope, composed of the highly-inclined slates. Above are vertical cliffs of red sandstone, conglomeratic below, which higher up again pass into another slope. The cliffs are undercut by the disintegration of the slates, which yield much more readily than the other rocks to the action of eroding agents. Large masses of the sandstone appear to break off from time to time, owing to the removal of their support. As has been remarked by Chandless (*3*), from the edge of the plateau the wide slate-plain looks like a sea, and the escarpment, with its inlets and promontories, has a curious resemblance to a coast-line. It is

[1] Above this point the Paraguay is an insignificant stream, it cannot be navigated in large canoes, and according to some authors is improperly called the Paraguay, (*5*) vol. i. pp. 107, 121.

[2] Sandstones with the same characters and probably of the same age are found on either side of the valley of the Rio São Francisco, where they form *chapadas* like that near Cuyabá, (*9*) pp. 32, 310, (*13*) p. 7. Similar sandstones also occur in São Paulo and the other Southern Brazilian States, (*11*) p. 254, (*13*) p. 8, as well as in the Chiquitos (see *infra*, p. 96).

not, however, necessary to have recourse to marine action for an explanation of the present configuration of the country.

The sandstones are of recent appearance and comparatively little consolidated, so that it is easy to understand why they were originally considered as being of Tertiary age. Red and white shales are found interstratified with them.

The Chapada Sandstones may extend as far west as Beira on the Rio Guaporé, at which locality similar sandstones were observed by A. d'Orbigny dipping south-east at an angle of 12° to 15°, (*1*) p. 203, a dip that is unknown elsewhere in these beds.

I am informed by Mr. C. H. Ward that the isolated hill known as Morro Grande, near São Antonio, on the Rio Cuyabá, a short distance below Cuyabá, is an outlier of the Chapada Sandstones.

Mr. Herbert H. Smith, who, as I have stated, spent two years in making zoological collections on the Chapada, found some fossiliferous sandstone in the bed of the Corrego dos Morrinhos, 4 miles north-east of Sant' Anna da Chapada:[1] this occurs near the summit of the Chapada Sandstones. According to Mr. Derby's description, (*8*) pp. 73–88, the fossils are in an imperfect condition, and only a few are specifically determinable. The following genera were identified:—*Lingula*, *Discina*, *Strophodonta*, *Tropidoleptus*, *Vitulina*, *Rhynchonella*, *Spirifer*, *Notothyris* (?), *Centronella* (?), *Bellerophon*, *Tentaculites*, and *Styliola*. Mr. Derby adds, "The specific characters, as far as they can be made out, show close relationship, if not perfect identity, with the fossils of Ereré on the Amazonas, and with those of the Hamilton or Middle Devonian Group of New York."

That author's paper contains an interesting discussion as to the relations between the rocks of Matto Grosso and those of the rest of Brazil. It also deals with the hilly region in Eastern Bolivia called the Chiquitos. This, Mr. Derby considers, belongs rather to the Brazilian highlands than to the Andes, (*8*) pp. 71–73, a view which I can confirm. In reading A. d'Orbigny's account of the Chiquitos (*1*) pp. 183–199, I recognized the chief types of rock that I had seen in Matto Grosso. They seem from his map and description to consist of a group of hills running east-south-east and west-north-west, due to an anticlinal axis lying in that direction, but rising towards the west-north-west, where gneiss comes to the surface in the centre, flanked by the Cuyabá Slates which form the centre of the anticlinal in the east-south-east. Outside these, but with a distinctly smaller dip, are found the Corumbá Limestone (sometimes similar to that which occurs at Coimbra) and the Rizama Sandstone.[2] Above are the Chapada Sandstones, patches of which lie unconformably and almost horizontally on the denuded anticlinal of older rocks. The Cuyabá Slates he calls Silurian, the limestone and Rizama Sandstone Devonian, and the Chapada Sandstones

[1] In the short time at my disposal in the Chapada I was unable to see this fossiliferous bed.

[2] Sandstone also occurs at the base of the limestone.

Carboniferous; and he compares these different deposits with the strata of the younger elevation of the Andes, in which later earth-movements have produced the same consolidation and modification as the earlier disturbances in the Brazilian region had done long before in its more ancient sedimentary deposits. A few isolated exposures of Rizama Sandstone appear to occur in the alluvium north and west of the Chiquitos; see (*1*) pp. 184, 197, and 200–201.

It may be suggested that the Rizama Sandstone and Matto Shales (unknown elsewhere in Brazil) are perhaps portions of the Chapada Sandstones and accompanying shales, which have been faulted down to their present position, outside and below the Chapada escarpment. I have come to the contrary conclusion, for the following reasons:—(*a*) The Chapada Sandstones are undisturbed and almost horizontal, within a comparatively short distance of the region where the Rizama Sandstone and Matto Shales have been affected by considerable earth-movements. (*b*) These latter rocks do not resemble the sandstones and shales of the Chapada. The difference seems too great to be accounted for as the effect of alteration, due to pressure accompanying disturbances. (*c*) In the Chiquitos it seems clear, from A. d'Orbigny's account, that representatives both of the Rizama and Chapada Sandstones are found, and that the latter are unconformable to the former.

The question can only be absolutely settled either by fossil evidence, or by following the Rizama Sandstone and Matto Shales to the north-east, and ascertaining whether they flatten out into the Chapada Sandstones, or—a more probable supposition—are covered unconformably by them.

VI.—7. Carboniferous (?)

Argillaceous shales with fossil ferns occur at Miranda on the river of the same name, one of the eastern tributaries of the Paraguay.[1] These, Mr. Derby thinks, are probably of Carboniferous age and correspond to fossil-bearing Carboniferous beds east of the Paraná, (*8*) pp. 66–67. He also thinks that rocks of the same age will ultimately be found on the Chapada plateau; see (*8*) p. 61.

8. Trias (?)

Above the shales is found, east of Miranda, a horizontally-bedded sandstone with eruptive basalt-like rocks.[1] Mr. Derby believes this to be identical with a similar sandstone exposed east of the Paraná, in which immense dykes and intercalations of augite-porphyrite occur, a sandstone which is regarded provisionally as Triassic; see (*8*) pp. 65–67.

[1] This information was obtained in the course of a survey of a proposed railway from Curitiba, on one of the western tributaries of the Paraguay, to Miranda, see (*4*).

9. Cretaceous (?)

Sandstone of the Taboleiros.[1]

According to Mr. Herbert H. Smith, (*8*) p. 63, this formation rests on the Chapada Sandstone and is perfectly horizontal. It has yielded vertebrate remains, among which Mr. Derby recognized a fragment of a turtle's carapace and a vertebra of another reptile. Mr. Derby says "it is possible, though not very probable," that these beds may prove to be identical with the sandstone with augite-porphyrite already referred to as possibly Triassic. He prefers, nevertheless, to class them with the Cretaceous beds in Eastern Brazil, (*8*) p. 68. It may be remarked that on the Purus, one of the southern tributaries of the Amazonas, and on its tributary the Aquiry, Upper Cretaceous beds with remains of turtle and *Mosasaurus* have been found; see (*9*) p. 494.[2]

VII.—10. Quaternary.

High-level Surface-deposits.

In the neighbourhood of Cuyabá and elsewhere, the Cuyabá Slates are frequently covered with a thick ferruginous deposit, consisting largely of pebbles of vein-quartz. The ferric oxide cement is abundant, and scoriaceous aggregates of the same material also occur. More or less laminated deposits of iron oxide are found on the Chapada, sometimes in such quantity as to render the soil unfit for vegetation. Ferric oxide is also widely distributed between the hills at Rizama and the river Paraguay, but I did not notice it to any large extent on the Matto Shales. It is found in the neighbourhood of the basaltic rocks at Tapirapuam.[3] Where these ferruginous deposits occur, there also goître and crétinism prevail. The rivers are usually highly charged with iron, the rock washed by them being often coated with a black deposit of iron oxide.

At Barra dos Bugres, high-level gravels occur in the hills some 20 metres (65 feet) above the Paraguay. The pebbles are exactly similar to those found in the present river-bed.

[1] *Taboleiros* are flat-topped hills.

[2] 'General Coûto de Magalhães speaks of the occurrence of fossil woods on the same tableland,' (*8*) p. 63. I found on the Chapada a fragment of ferruginous material full of elongate cavities; it certainly has the appearance of wood, but was probably formed inorganically by the deposition of iron oxide. Angiosperm wood occurs fossil near Coimbra, *op. cit.* p. 64.

[3] These ferruginous deposits are known in Brazil as *canga*. Mr. Derby suggested in a letter to me that they were identical with the laterite of India. This is, to a large extent, true; but both terms are loosely employed.

Alluvial Deposits.

The lowland plains and swamps are composed entirely of alluvium, though penetrated here and there by elevations of the older rocks. The rivers bring down from the hills a vast amount of detrital material, especially in flood-time. When a stream overflows its banks, the luxuriant vegetation on the margin catches up and entangles most of the matter held in suspension, so that a strip adjoining the river is raised higher than the ground farther away. In some localities remote from the course of the principal rivers permanent lakes of considerable area occur. In the time of high water, which lasts for about six months in the year, these lakes appear to be merged in the extensive sheets of water (*xaraes* or *pantanaes*)[1] which unite the courses of the Paraguay and of its tributaries the São Lourenço, the Cuyabá, and others, and cover almost all the alluvial plains. These facts point to the former existence of a great lake or lakes (comparable to those of Equatorial Africa or North America) which have been subsequently filled up by alluvium.[2]

The alluvial deposits are in some places cut into by the rivers, and sections are thus afforded. These occasionally contain thick shell-bands of a large *Ampullaria*, apparently identical with one that now inhabits the adjoining swamps.

VIII. Unclassified Rocks.

At Urucúm, near Corumbá, I found, overlying the ancient igneous rocks and probably also the Corumbá Limestone, deposits almost entirely composed of oxides of iron and manganese. They form a hill some 600 metres (1950 feet) high, and 5 or 6 kilometres (3 or $3\frac{3}{4}$ miles) long. Some of the neighbouring hills appear to be of similar composition, although it is said that they do not contain so much manganese. The strata form a gentle synclinal. They seem to be fragments of former more extensive deposits (probably lacustrine), and to owe their preservation to the accumulation at this point—the centre of a synclinal—of the above-mentioned oxides, which have proved more durable than the rest of the deposits.[3]

These rocks appear to be younger than the Corumbá Limestone, but are probably older than the Chapada Sandstones, for they have suffered more from earth-movements. They may, perhaps, be a local phase of the Matto Shales.

Massive siliceous iron ore, with geodes lined with quartz, occurs near Coimbra, but I have not seen it in place.

[1] [Perhaps here *xaraes* = *charcos*, and *pantanaes* = *pantanos*.—Ed.]

[2] A similar process, on a much smaller scale, is now going on in the district of the Norfolk Broads, (*21*) p. 353.

[3] From the description given me at Uacurisal (a locality on the Paraguay already referred to) of the rocks in the hills near Gahyba, farther north, it seems not improbable that they may be similar to those at Urucúm.

IX. Igneous Rocks

I have already referred to the ancient igneous rocks of Corumbá. Von den Steinen found a granitic zone on the Xingú, 10° lat. S., which may, perhaps, be of similar antiquity, *(6)* p. 133.

I met with an interesting augite-syenite at the Pão d'Assucar. This, as its name implies, is a sugar-loaf shaped eminence on the eastern bank of the Paraguay, about 21° 25′ lat. S. It is one of a group of hills rising out of the alluvial plain on either side of the river.[1] The rock contains orthoclase somewhat altered, a little plagioclase, brownish-green hornblende, green augite, biotite, abundant sphene (in fairly large crystals visible to the naked eye), and apatite. As is sometimes the case in augite-syenites, the biotite may often be seen surrounding the augite. The sphene is occasionally formed round the hornblende as a nucleus.

Mr. Orville A. Derby, to whom I sent a fragment of this rock, tells me that it closely resembles certain augite-syenites associated with the nepheline (elæolite)-syenites of Eastern Brazil, which he has described, *(15)* p. 457, *(16)* p. 311, and *(17)* p. 251. I could not detect elæolite in thin sections of the rock, though it shows some gelatinization on treatment with acid; possibly there may be some too small to be recognizable, or such small particles as once existed may have passed into some alteration-product. A nepheline-basalt is reported from Paraguay at no great distance to the south, *(14)* p. 247.

About 6 kilometres (3¾ miles) south of the Pão d'Assucar is another exposure of somewhat similar rock. This is much altered, with secondary quartz; plagioclase-felspar is predominant.

Mr. Derby has shown that the elæolite and augite-syenites of Eastern Brazil are either late Carboniferous or post-Carboniferous. The Pão d'Assucar rock will prove to be of the same age, if, as is believed, it is a distant representative of this important petrographical province of nepheline-bearing rocks, which extends in the opposite direction as far as the island of São Fernando da Noronha.

If, as seems likely, the basalt-like rocks of South-eastern Matto Grosso are identical with the widespread augite-porphyrites on the other side of the Paraná, they will be at least post-Carboniferous, and probably of still later age.

The Tapirapuam rock is a rather coarse basalt, approaching a dolerite. It contained abundant olivine, now altered into serpentine and ferric oxide. Many of the felspars are ophitically included in the larger augites. Most, however, occur among granular augite, or embedded in opaque material consisting largely of magnetite, ilmenite, and leucoxene. There is no evidence of the age of this

[1] The 'closing of the hills' upon the river at this place has suggested the name, Fecho dos Morros.

rock, except that it is probably younger than the Matto Shales. I had, unfortunately, no opportunity of determining whether it occurred as a dyke or as the outcrop of an intrusive or interstratified rock. In connexion with this basalt, Mr. Derby writes to me:—"Dykes, often of considerable size, of similar rocks are common in the Devonian and Carboniferous regions of the Amazonas and of São Paulo and Paraná, as well as in the regions characterized by the older rocks."

X. Historical Summary.

It may not be out of place here to briefly detail the succession of conditions indicated by the geological structure of Matto Grosso and the surrounding regions.

At a remote period the materials now forming the Cuyabá Slates were deposited over an extended area. In some places we have indications of the neighbourhood of land, consisting mainly of the, even then, ancient crystalline rocks, which had already assumed the characters that they now possess. Then came a period of great earth-movements resulting in the folding, cleavage, upheaval, and denudation of the slates. Subsequently, after depression had occurred, the Corumbá and Arara Limestones were widely deposited on the crystalline rocks and upturned edges of the Cuyabá Slates. Thenceforward there is progress to continental conditions. The Rizama Sandstones and Matto Shales were deposited in successively diminished areas, perhaps in freshwater basins.[1] A second series of movements (which had probably commenced at the close of the deposition of the limestones) now moulded all the then existing rocks into the continental mass that still forms the framework of the Brazilian highlands. As none of these rocks yield fossils, we can say nothing concerning the period when these events took place. In Silurian times we find the sea covering the region west of Brazil, where the Andes were subsequently uplifted, and also occupying the Amazonas depression between the large islands now represented by Guiana and Central Brazil: see *(10)* p. 160. In the Devonian period general depression prevailed, during which extensive deposits were laid down on the denuded surface of the old rocks. The depression continued to some extent during the Carboniferous period. The land then again rose, and since that time land conditions have mainly prevailed. The sandstones of the Taboleiros and similar rocks in other parts of Brazil seem to be local freshwater deposits; it is only on the sea-border that marine Secondary strata are found. From the Devonian period to the present time the horizontality of the rocks seems to have been (except at a few points on the margin of the continental *massif*) almost entirely undisturbed;

[1] The Matto Shales especially have the appearance of being of freshwater origin.

and this in spite of the fact that, in the adjoining region to the westward, the comparatively recent elevation of the Andes has been accompanied by earth-movements of the greatest magnitude, involving rocks of all ages.

It is interesting to compare the geology of South America with that of Southern Asia. There also enormous foldings have taken place in connexion with the elevation of a great mountain-chain in late geological times on the margin of an ancient land region, that has since remote ages remained practically undisturbed, except by the repeated intrusion and eruption of igneous rocks. This region is, of course, peninsular India, which geologically presents many points of resemblance to Brazil. Indeed, most of the formations of the two countries may (to coin a new but self-explanatory phrase) be considered 'tectonically homotaxial,'[1] or structurally equivalent, to each other. Thus the 'Metamorphic' corresponds to the ancient crystalline rocks of Brazil. The 'Transition' represents the Cuyabá Slates; while the Vindhyan represents the Corumbá and Arara Limestones and the Rizama Sandstone. The later Brazilian rocks present points of resemblance to the Gondwana group. It is doubtful whether the rocks I have compared are in any case contemporaneous with one another—in fact, their ages may be widely different; but they have taken a similar part in the building-up of the present land.

XI. Economic Products.

Gold has mainly been worked in the ferruginous conglomeratic deposits overlying the Cuyabá Slates. These deposits have, through a wide area, been completely turned over in the search for the precious metal. They are now neglected, although a few streams, such as the Coxipo, are occasionally worked. Most of the quartz-veins that penetrate the slates are not very auriferous, but I was told that some reefs gave good results. Gold is said also to be found in the Chapada Sandstones, especially where there have been well-marked breaks in the deposition.[2]

Diamonds.—These are found in deposits practically identical with the alluvial workings in other parts of Brazil. They are chiefly obtained from the valleys of two tributaries of the Paraguay, the Rio Diamantino and the Rio Sant' Anna, and the tributaries of the

[1] [Two formations (in different countries of similar geological structure) will therefore be 'tectonically homotaxial,' when they come into existence at the same stage in the development of that structure, although they may not be identical in actual age or fossil contents.—January, 1894.]

[2] In a watercourse on the Chapada, north of Sant' Anna da Chapada, I found a small fragment of rock, which was stated by a negro who accompanied me to be a specimen of the rock from which gold and diamonds are obtained. In colour it is greenish-grey, weathering to yellowish-red. A great part of its volume is made up of cavities, in shape and size like the grains of very fine oolite. Most of the cavities are partly filled with crystalline quartz, and some

latter. I have not visited the workings, which have to a large extent been discontinued since the abolition of slavery, as the work is very unhealthy. The following details of the deposits are summarized from Castelnau, (*2*), 1ère Partie, vol. ii. pp. 319–343:—

4. Black argillaceous earth.
3. *Gorgulho.* Small sandstone and quartz-pebbles cemented by yellow clay.
2. *Cascalho.* Larger pebbles without cement.
1. Red argillaceous shales (probably Matto Shales).

In No. 2 are found, in addition to the constituents of No. 3, a black or mottled quartz, a fine hone-like sandstone (probably derived from the Rizama Sandstone), a violet sandstone, and diamonds. The three former are regarded as indicators of diamonds. I found similar pebbles in the Paraguay and its tributaries at and above Barra dos Bugres, but saw no diamonds.[1] Castelnau states that sandstones occur in the vicinity of the workings; from these he supposes the diamonds to have been originally derived.

Iron occurs in abundance, especially at Urucúm.

Manganese is also found at Urucúm, where it occurs in thick deposits, which appear as a band of black cliffs halfway up the mountain.

Copper (on the Rio Jauru), *lead*, and other metals are stated to occur, (*5*) vol. i. p. 148.

In conclusion, I may mention that specimens and thin sections from the principal localities which I visited are deposited at the British Museum (Natural History), South Kensington.

EXPLANATION OF PLATE VIII.

Geological Map of a Portion of South-eastern Matto Grosso.

Note.—The alluvial region shown in the map is a vast stretch of swampy lowland, which is under water during great part of the year. For 'Livramenta' read 'Livramento.' The position of Arara is on the limestone-outcrop south of the Rio Ciripuru, and west of Livramento.

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entirely so. The matrix is ferruginous and highly magnetic. An analysis by Mr. G. T. Holloway gave the following results:—

	Per cent.	
Silica	95·970	=100·665
Iron .... 2·690 corresponding to Magnetite	3·710	
Alumina	·423	
Lime	·460	
Magnesia	·102	
Manganese	traces	
Phosphoric acid	traces	

Mr. Derby tells me that it resembles a weathered specimen of a pyritiferous quartz-veinstone from Minas Geraes. The pyrites appears to have been removed, and additional silica deposited in the cavities left. He thinks that such a rock may be auriferous, but is not likely to contain diamonds.

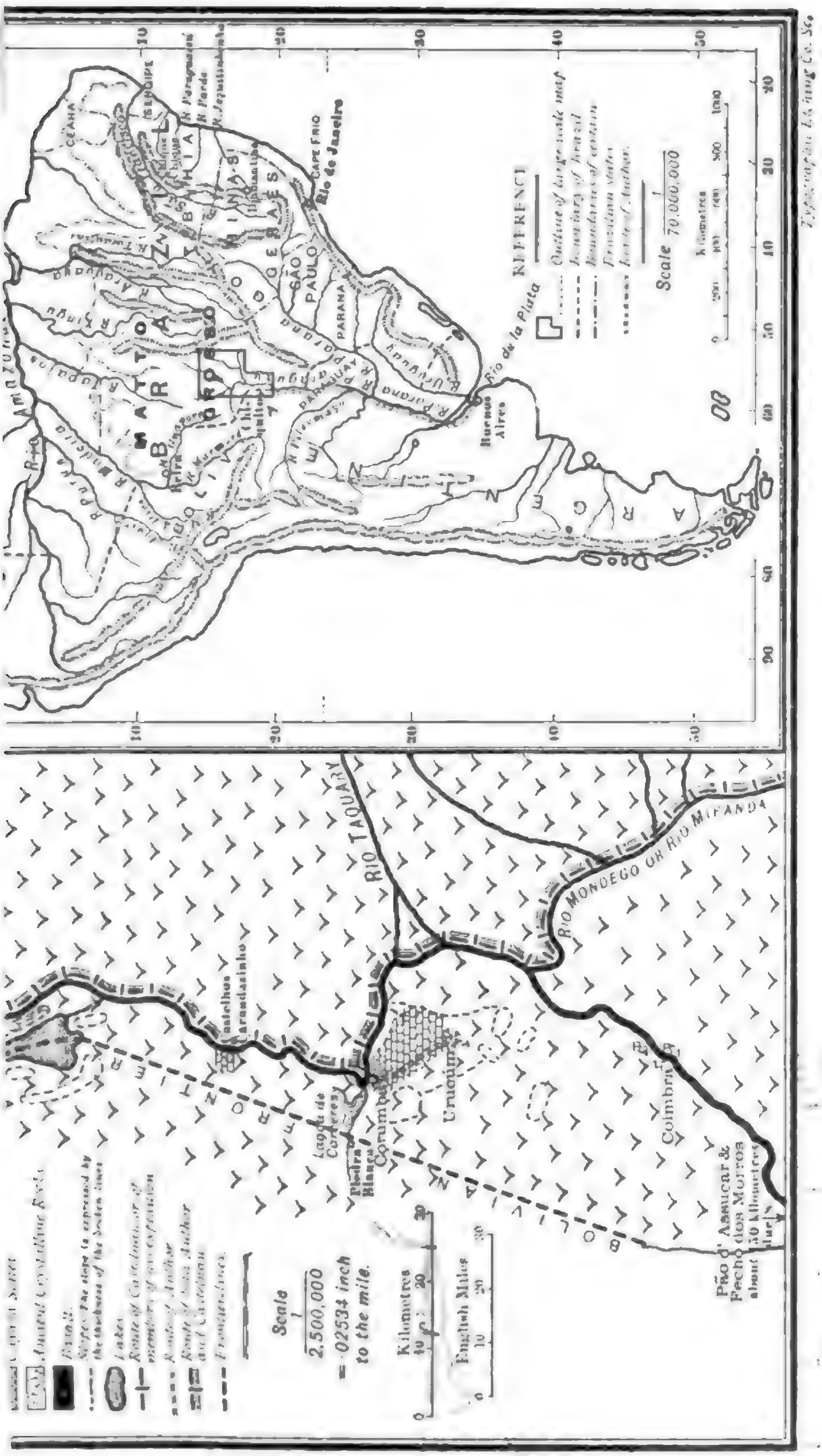
[1] A small crystal of topaz with rounded edges was found there.

Discussion.

The President pointed out that it would be wrong to judge this paper by the ordinary standard. It might be described as a record of the results of a geological reconnaissance in a comparatively unknown country.

Mr. Spencer Moore, fellow-traveller with Dr. Evans in Matto Grosso, gave a brief sketch of the fortunes of the recent expedition to that province. In the course of his remarks, Mr. Moore dwelt on the difficulties met with; difficulties so great that it was matter for congratulation that Dr. Evans had been able to make out so much of the structure of the districts visited.

Mr. H. Bauerman and Mr. R. D. Oldham also spoke.


RIO TAQUARY
RIO MONDEGO OR RIO MIRANDA
Corumba
Urucum
Coimbra
Pão d' Assucar & Fecho dos Morros
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Kilometres
English Miles
MATTO GROSSO
MINAS GERAES
BAHIA
SÃO PAULO
PARANA
CEARA
Rio de Janeiro
Cape Frio
Buenos Aires
Rio de la Plata
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9. *The* Geology *of* Bathurst (New South Wales). By W. J. Clunies Ross, Esq., B.Sc., F.G.S. (Read November 8th, 1893.)

Contents.

I. Introduction.

Bathurst may be regarded as the centre of a district of considerable geological importance, not alone as an isolated area in the Australian colonies, which might be considered of merely local interest, but because of its relationship to other areas. The solution of the problems connected with its stratigraphy and petrography may, therefore, contribute in no small degree to decide the age and relative positions of many of the older rocks of New South Wales, and enable us to correlate them with those of Victoria, on the one side, and Queensland, on the other.

The late Rev. W. B. Clarke, F.R.S., long ago pointed out the fact that all the older stratified rocks of Eastern Australia have a general north-and-south strike, which can be traced from Victoria, through New South Wales, to Queensland. This important generalization is the key to much of Australian geology. When we ask, however, what is known of the relationship of the rocks of the various colonies, or even of different parts of the same colony, it must be admitted that much still remains to be done.

In Victoria, it is true, rocks belonging to the Lower and Upper Silurian have been recognized, and a thick series in Gippsland has been classed as Lower, Middle, and Upper Devonian by Mr. A. W. Howitt, F.G.S. In New South Wales the distinction between Silurian and Devonian rocks has not been so clearly made out, and over a large area the strata have been provisionally classified as Siluro-Devonian. Moreover, while there is uncertainty as to the base of the Devonian system, there is also a good deal of doubt as to its upper limit; and it has been suggested that many rocks formerly classed as Devonian should be placed in the Lower Carboniferous.

Both Silurian and Devonian rocks are well developed in the neighbourhood of Bathurst, where they form two very distinct series, and as many of them are similar in character and fossil

contents to those found elsewhere, a clear knowledge of the stratigraphy of the district will enable one to classify the beds in other parts of the colony, by establishing a distinction between those belonging properly to the Silurian and those which are Devonian; and, further, to separate the latter from the Carboniferous. Under these circumstances it is thought that a short account of the geology of the Bathurst district may be of interest, not only to Australian geologists, but to those who reside in other parts of the world.

II. Previous Work on the Subject.

Very little has been done, or at any rate published, in reference to Bathurst geology. In the writings of the Rev. W. B. Clarke and others there are a few scattered notices. The late Mr. C. S. Wilkinson, F.G.S., also alluded to it,[1] and the same gentleman carefully surveyed the country around Rydal, about 28 miles east of Bathurst, and published a geological map and section of that area.[2] The work is well done and is very interesting, but unfortunately no detailed account of the country seems to have been written. In 1891 the Rev. J. M. Curran read a paper before the Linnean Society of New South Wales, which he subsequently published in pamphlet form.[3] The paper mainly treats of the petrography of the Bathurst rocks, although the stratigraphy of the district is also dealt with to some extent. Apart from these papers, and one or two which the present writer has contributed to the Australasian Association for the Advancement of Science, nothing, so far as he knows, has been published on the subject.

III. Physiography of the District.

Bathurst, a city of about 10,000 inhabitants, is situated 140 miles west of Sydney, N.S.W., at a height of about 2100 feet above sea-level. It is nearly in the centre of what are known as the Bathurst Plains, a tract of undulating country surrounded by hills, which rise to a height of 1000 to 2000 feet above the city. The Plains are about 20 miles across from east to west, and rather less from north to south. The Macquarie river runs by the city and is formed by the confluence of two streams—the Fish and Campbell rivers, which unite to form the Macquarie about 6 miles above Bathurst. The river is fed by a few creeks, one of which, the Vale Creek, skirts the south side of the town and is of moderate size. The Macquarie has a long course, flowing past the towns of Wellington and Dubbo, to the north-west of Bathurst, and, ultimately, its waters form part of the Darling system, and find their way to the Indian Ocean by the Murray. Near Bathurst the river flows in a wide and deep

[1] 'Notes on the Geology of New South Wales,' Sydney, 1882, pp. 39 and 62.

[2] Annual Report of the Department of Mines for 1877, Sydney, 1878.

[3] 'A Contribution to the Geology and Petrography of Bathurst, New South Wales,' Proc. Linn. Soc. N.S.W. ser. 2. vol. vi. pp. 173–234, & pls. xiv.–xviii.; sep. cops. published by Angus and Robertson, Sydney, 1891.

channel, and in time of flood is a fine stream. For the greater part of the year, however, it only fills a small part of its bed. The hills to the east are drained mainly by the Wimburndale Creek, which has a course of considerable length, and enters the Macquarie a long way below Bathurst. Near the centre of the Plains, and about 2 miles south-west of the city, are the Bald Hills, about 650 feet high, capped by a mass of basalt, 200 feet thick; beneath this is a layer of drift-gravel, which in places has been cemented into a compact conglomerate. There are also several terraces of gravel, capping the lower hills and running roughly parallel to the course of the river.

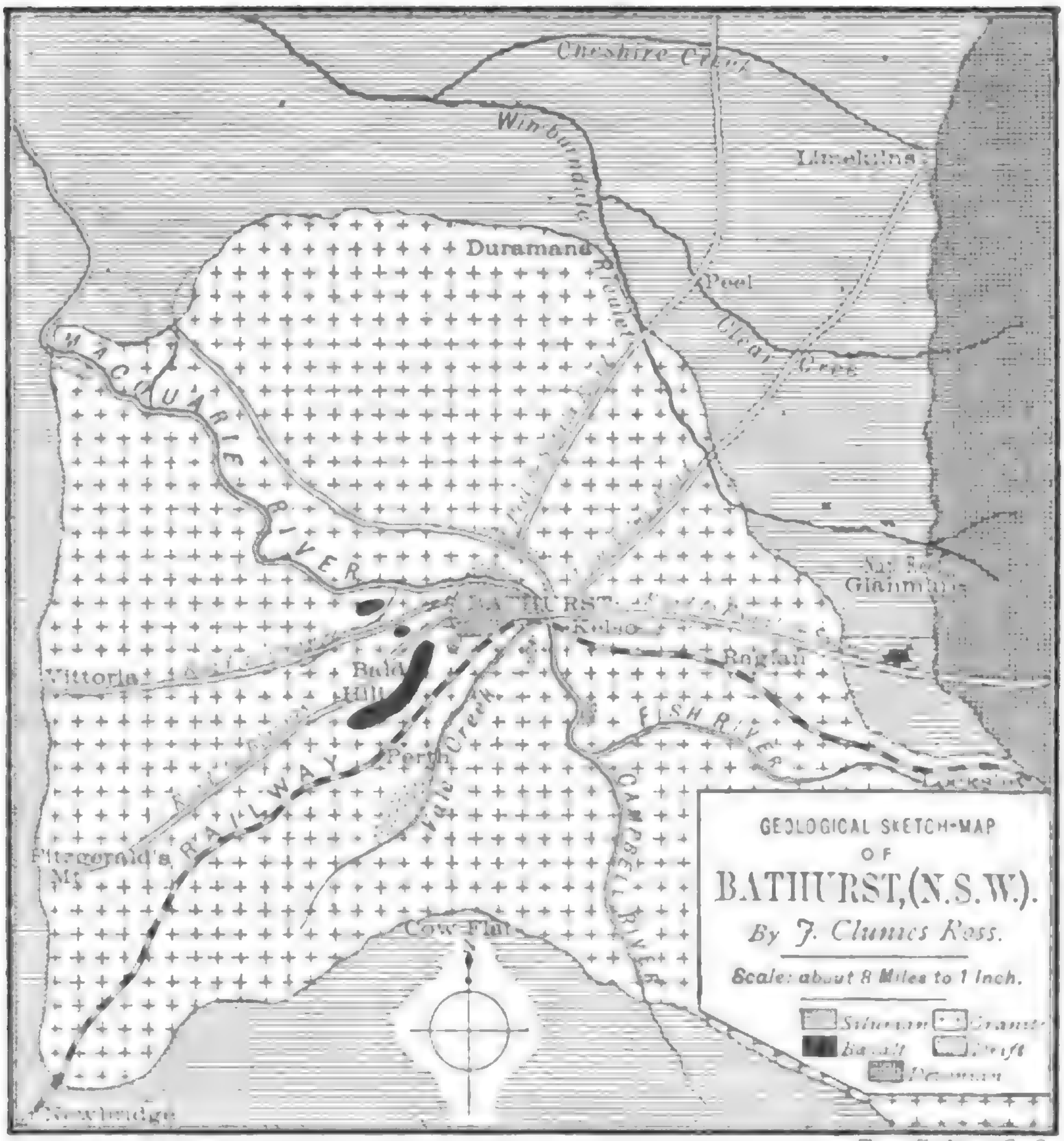
The Bathurst Plains form an extensive granite area, estimated at 450 square miles, while the hills, which rise at an average distance of 10 miles from the city, are formed of metamorphic rocks. The granite can be followed on the surface, however, for a much greater distance around the valley of the Fish River and its tributaries. The metamorphic rocks consist partly of highly altered rocks, such as crystalline marbles, mica- and hornblende-schists; partly of less altered varieties, such as massive slates and silky schists, with, in places, beds of limestone containing many fossils. They are probably all Silurian, but east of Bathurst they are backed by a bold escarpment of Devonian rocks, consisting mainly of quartzites and sandstones. These attain a height of 4000 feet above sea-level, but appear to be absent from the north, south, and west of Bathurst. Mr. Curran states that the Devonian is overlain by Carboniferous beds, but no rocks of that age are known to the writer as occurring around Bathurst. (See Map and Section, pp. 108, 109.)

IV. Detailed Geology of the District.

1. The Central Area.

The granite over the greater part of the country is much decayed near the surface, owing to the decomposition of its felspar. It often appears compact enough where exposed on the banks of creeks and in road-cuttings, but crumbles down at once when touched with the hammer. In places, however, the granite is hard and compact, and consists of light-grey felspar, quartz, black mica, and very often hornblende, with sphene and apatite as accessory minerals. It is mostly rather coarse-grained, with, in some localities, large crystals of pale pink orthoclase, porphyritically developed.

At the Waterworks, Bathurst, small veins of calcite and prehnite occur, developed along the joint-planes of the solid granite. When examined microscopically, most sections show a good deal of plagioclastic felspar, probably oligoclase, so that the rock might be called a granitite, and affinities are suggested with the quartz-mica-diorites of Gippsland, Victoria, described by Mr. Howitt. Some of the large crystals of orthoclase show interesting instances of zones of growth around the outlines of the crystals, and also a cross-hatched structure suggestive of microcline.



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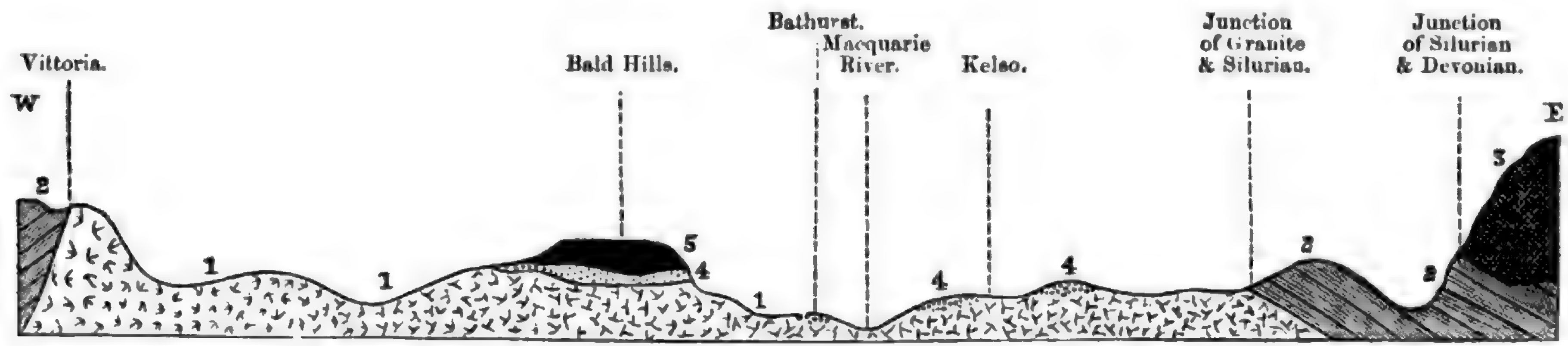
Note.—The only geological map of New South Wales, as a whole, yet published is that which accompanies Mr. Wilkinson's 'Notes on the Geology of New South Wales.' It is based on the original map compiled by the Rev. W. B. Clarke, F.R.S., and is on a scale of about 30 miles to 1 inch, of course much too small to display detailed geology. On it the limits of the Silurian and Devonian rocks are certainly not drawn correctly for the neighbourhood of Bathurst.

The accompanying sketch-map has been drawn up by the writer from his own observations, and, although on a small scale, is yet, it is believed, sufficiently clear to enable the geology of the district, which is comparatively simple, to be understood. The zone of rocks highly altered by contact-metamorphism was symbolized in the original sketch by a thick line drawn round the junction of the Silurian and the granite, but this has been unintentionally omitted by the draughtsman who recopied the map. For 'Nap Reef' read 'Napoleon Reef;' for 'Glanmure' read 'Glanmire.'

[Since this paper was written, a new geological map has been issued by the Department of Mines, N.S.W. It is on a scale of about 15 miles to the inch, and is in all respects a great improvement on the old one.]

Section across the District of Bathurst (New South Wales).



Scale: Horizontal, 1 inch = 5 miles; Vertical, 1 inch = 2000 feet.

1. Granite.
2. Silurian.
3. Devonian.
4. Gravels (Drift).
5. Basalt.

The above section illustrates the principal undulations of the ground, although the vertical scale is, of course, much exaggerated when compared with the horizontal.

Scattered through the mass of the rock are patches of fine-grained granite, largely composed of black mica. The rock is traversed, moreover, by veins of a granite differing considerably from that which surrounds them. These veins are common in the decomposed granite, but have themselves apparently undergone very little decay. Some are very fine-grained, while others are excessively coarse, and these often occur very close together. All are alike made up of quartz and pink orthoclase, often coated with scales of nearly white mica.

Near the boundary of the granitic area there is a change in the rock, and it approaches in character that found in the veins, the biotite and hornblende disappearing or becoming scarce, the former being replaced by muscovite, and the felspar being of a reddish tint.

At certain localities in the district several other varieties of granite occur. Thus, at Locksley, about 15 miles east of Bathurst, there is a fine porphyritic granite, very similar in appearance to the Shap granite of Westmoreland, and at Sarana, still farther east, there is a rock composed of white felspar and quartz, with little mica, approaching a pegmatite in appearance. The granite near the boundary of the metamorphic area affords good examples of granophyric or micro-pegmatitic structure.

2. The Age of the Granite.

One can hardly speak with much confidence as to the age of the granite. It is clearly newer than the Silurian rocks, since it sends veins into them, and there is a broad zone of rocks altered by contact-metamorphism surrounding the granite. Whether it is newer, as a whole, than the Devonian rocks is doubtful. The latter are certainly folded to some extent, but not nearly so much as the Silurian. They are traversed in places by what appear to be intrusive dykes of felstone, highly siliceous, and often porphyritic. In some cases they rest directly on the granite, and at Rydal the late C. S. Wilkinson described them as being altered at the contact. Near Lithgow the granite is overlain by rocks of Carboniferous and Permian age.

On the whole, the writer is inclined to think that the granite is not all of the same age. The first intrusion may have taken place subsequent to the deposition of the Silurian, but prior to that of the Devonian rocks, and there may have been a second intrusion, accompanied by further tilting and crumpling of the Silurian and disturbance of the Devonian strata, which sent veins of felstone into them, and converted many of the sandstones into quartzite. The different character of the granite at the centre and near the boundary of the area seems to support this view, although it is not easy to draw any boundary-line between the two types; but this may be owing to the fact that most of the country is covered with soil and under cultivation, so that good exposures are only attainable at places some distance apart. The series of veins which

traverses the central mass of granite is probably connected with the second intrusion.

In the New England district, Northern New South Wales, Prof. T. W. E. David, F.G.S., recognizes granitic rocks of at least two ages.[1] In Victoria most of the typical granites are classed as newer than the Silurian, but older than the Upper Palæozoic strata.[2]

A fairly typical specimen of the biotite-granite, from the Waterworks, Bathurst, gave on analysis 68·5 per cent. of silica; its specific gravity was 2·75 to 2·79. Granite close to the junction with schist yielded 73·5 per cent. of silica. Specific gravity 2·59 to 2·62.

3. The Silurian Rocks.

Very good exposures of the junction of the granite with the overlying rocks occur at many localities around Bathurst, and one is at once struck by the similarity of the contact-rocks when examined at places as much as 20 miles apart. The metamorphic rocks at the contact differ to some extent among themselves, as to fineness of grain and in other ways, but they are nearly all of the same type—namely, a kind of hornblende-schist, although they can hardly be called typical schists. Most of them are tolerably coarse-grained, but some are so fine that they appear like quartzite or fine-grained felstone. Under the microscope they are seen to consist largely of quartz, with a good deal of a green mineral, strongly dichroic, but not usually occurring as distinct crystals or showing cleavage-lines. It is probably altered hornblende, the rock having evidently undergone much change from its original condition. Perhaps the best name for the contact-rock is hornfels, as suggested by Mr. Curran.

An average specimen of this rock, from the Wimburndale Creek, near Peel, gave 66 per cent. of silica; granite from the same locality yielded 73·5 per cent. The specific gravity of the hornfels varies from 2·75 to 3. A collection of the contact-rocks was shown by the writer to Mr. A. W. Howitt, F.G.S., who remarked that he could match them all from Gippsland, Victoria.

In all cases the junction is sharp and well defined, there being no instance known to the writer in which there is any indication of a gradual passage from the granite to the hornfels, such as would suggest that the granite had resulted from the extreme metamorphism of the overlying rocks. There is often a creek running roughly parallel to the junction, so that the line of contact may be followed for a considerable distance at several localities. The line is an irregular one and winds about in a curious manner: the granite often sending small veins into the metamorphic rock, so that there can be no possibility of a faulted junction. The

[1] 'The Geology of the Vegetable Creek Tin-Mining Field,' by T. W. Edgeworth David, F.G.S., Department of Mines, N.S.W., 1887.

[2] 'Victoria—Geology and Physical Geography,' by Reginald A. F. Murray, Melbourne, 1887, p. 24.

writer possesses a microscopic section taken exactly across the junction, and the contrast between the granite, with felspar but nothing approaching hornblende, and the hornfels, with no felspar but much of the green mineral, is very striking.

Outside the altered contact-zone the character of the rocks varies considerably. South of Bathurst there is an area of highly altered rocks. These are mainly micaceous and hornblendic schists, which in places contain felspar and become gneissic in character. Interbedded with them are crystalline limestones, pure white or with bluish markings, mostly rather coarse-grained, but often well suited for ornamental purposes as marbles. These rocks are generally nearly vertical, and often much crumpled. In places they contain copper ore, which has been worked to some extent at a locality known as Cow Flat. North of Bathurst similar rocks occur, but they are, as a rule, less altered, many having the character of massive slates rather than schists.

The metamorphic rocks north and south of Bathurst are so much altered that it is difficult to form an idea as to their age. Cambrian rocks are known to occur in Tasmania and South Australia; while Lower Silurian strata are extensively developed in Western Victoria, and, in the eastern part of that colony, some of the Silurian rocks of Gippsland have been provisionally referred to the same age, although it is admitted that the determination is somewhat doubtful.[1] As the strike of the beds there is north and south, they might be expected to pass into New South Wales, but hitherto no beds of Lower Silurian age have been definitely recognized in this colony. Some of the Bathurst rocks may eventually be proved to be of that age.

East and west of the town the rocks are less altered than on the north and south. At several places the hornfels is succeeded by spotted schists, very much like some of the rocks near the Skiddaw granite of Cumberland, but the chiastolite-slate, so well known there, has not yet been found in this district.

The spotted rock passes into silky schists, and these into massive slaty rocks, seldom showing distinct cleavage. No fossils have yet been found in the slates, although some of them look promising and may repay further search. At Limekilns, about 16 miles north-east of Bathurst, there is, however, a bed of limestone, apparently interstratified with the slate, and this contains many fossils in good preservation. It is a bluish limestone, about 50 feet thick, the strike being N.N.E. and the dip W.N.W., about 30°, but variable. Some of the layers are largely made up of encrinite-stems, but others consist mainly of corals. Of these Mr. Curran mentions *Stromatopora striatella*, *Favosites fibrosa*, and *Petraia*, sp.; also a new species of *Phillipsastræa*, which has been described by Mr. R. Etheridge, Jun., and named *P. Currani*.[2] There are several other corals, including, probably, *Favosites gothlandica*, and also brachiopoda. The latter have not been systematically described,

[1] 'Victoria—Geology and Physical Geography,' R. A. F. Murray, p. 42.
[2] Records Geol. Surv. N.S.W. vol. ii. pt. iv. (1892) p. 166, pl. xi.

but the writer has found indications of a *Pentamerus*, probably *P. Knightii*. This fossil, *P. Knightii*, is also found in other parts of the colony; as at the celebrated Jenolan Caves, which are situated about 50 miles E.S.E. of Bathurst; at the Yarrangobilly Caves, in the extreme south of the colony; about Yass, and elsewhere. It is, of course, a very well-known Upper Silurian fossil in Europe, and its occurrence in New South Wales goes far to stamp the beds in which it is found as of approximately the same age. Mr. R. Etheridge, Jun., believes that it characterizes a particular horizon in this colony.[1] Should this prove to be the case, the fossil will be very useful, by enabling us to correlate the various beds of limestone, together with the beds interstratified with them, at a large number of places. The other fossils at Limekilns lead one to the same conclusion, and the limestone has therefore been generally recognized as of Upper Silurian age.

At Rockley, about 20 miles south of Bathurst, there is a blue limestone much resembling that at Limekilns, but composed almost entirely of encrinite-stems. It will very likely prove to be of the same age.

The Silurian strata on the east side of Bathurst generally dip eastward, although occasionally the dip changes to west owing to folding. On the western side the dip is westerly, so that there appears to have been a great anticlinal fold over what are now the Bathurst Plains, which has been completely denuded away from that area. One would expect in this case to find a repetition on the west of the beds which occur on the east; but, owing to the great similarity of the different beds of slaty rocks, it is extremely difficult to recognize outcrops of the same bed at a distance from one another. The limestones would be more likely to be recognizable, but unfortunately these appear to exist rather in lenticular masses than in extensive beds, so that it is doubtful whether much assistance will be obtained from them.

Quartz-reefs are very common in the Silurian rocks around Bathurst. Many of them are auriferous, but few contain enough gold to repay working, although some of the richest alluvial workings in the colony have been situated not very far away, as at Sofala, about 25 miles N., and Hill End, 30 miles N.N.E., where reef-mining has also been extensively carried on. During the last year or two successful attempts to extend some of the old workings have been made; among other places, at the Napoleon Reef, about 10 miles east of Bathurst.

Veins, other than quartz, are not uncommon. They mostly, like the quartz-reefs, follow the general strike of the country rocks and appear to be interbedded with them; and, as they have evidently undergone much alteration, it is often difficult to say whether they are intrusive, or have resulted from local changes in some of the sedimentary beds. One such vein, at Glanmire, 10 miles east, is seen under the microscope to have a matrix of quartz, crowded with

[1] 'On the Pentameridæ of New South Wales,' Records Geol. Surv. N.S.W. vol. iii. pt. ii. 1892.

minute crystals of, probably, epidote, surrounding large green crystals. The specific gravity of the rock is 3·04.

The strike of the Silurian strata varies from N.N.W. to N.N.E., sometimes changing within a short distance.

4. The Devonian Rocks.

The passage from Silurian to Devonian beds is not easy to observe near Bathurst, and an actual section showing the junction has not yet been met with by the writer. Nevertheless, there is a distinct change observable, both in the character of the rocks and the nature of the country, when passing from one series of rocks to the other; and an alteration in the flora may also be noted, the Silurians being richer in species of plants than the Devonians.

On travelling eastward from Bathurst, one passes over low hills of granite and then reaches the Silurian rocks, which rise into higher hills with a comparatively gentle slope, followed by a fall in the ground to a creek, where one is again at about the level of the city. Once more the ground rises, still with a gentle slope, and the ground is covered with downwash from the hills beyond, so that good exposures of the rocks are not common. Where seen, however, they are still slaty or schistose rocks of the Silurian type. Then the slope becomes much steeper, rising to a height of about 1000 feet, and, on working up the face of the escarpment, one immediately notices that the slates have entirely disappeared, the rocks consisting mostly of massive beds of quartzite and grit, with intrusive sheets of felstone. The summit of the escarpment is in some places a thick bed of conglomerate formed of well-rolled pebbles of, mostly, hardened slate, but mixed with others of more siliceous rocks. The conglomerate does not extend very far if followed along the strike, and elsewhere the highest beds are of grit. The strata dip eastward into the hill at an angle varying from 10° to 30°. By following the course of a creek which runs nearly east and west, some very fair sections may be observed, and the beds are found to be undulating, occasionally dipping west; the whole appearance of the rocks contrasts markedly with that of the Silurian strata, to which there can be little doubt that they are unconformable.

The grit-beds, interstratified with the quartzites, are largely made up of the casts of brachiopoda, notably *Spirifer disjunctus* and *Rhynchonella pleurodon*, so that they are often called the 'Brachiopod Sandstones.' There are, however, a few corals and other fossils as well, including a *Lepidodendron*, which is of interest, since there has been some doubt as to whether it occurred in these rocks or not.

Among the fossils enumerated by the late C. S. Wilkinson, F.G.S., from the Devonian beds of Rydal is *Lepidodendron nothum*, Unger.[1] Dr. Feistmantel, in describing the older fossil plants of the

[1] 'Notes on the Geology of New South Wales,' p. 42.

Australasian colonies,[1] also mentions it as occurring in various parts of New South Wales and Queensland. In Victoria a species of *Lepidodendron* occurs which has been described by Prof. M'Coy as *L. australe*.[2] It is now contended by Mr. R. Etheridge, Jun., and others that the true *L. nothum* does not occur in the colonies at all, but that the specimens so described should be classed as *L. australe*. The question is ably discussed by Mr. Etheridge in a paper published in 1891.[3] The rocks in Victoria containing *L. australe* have been provisionally classed as Lower Carboniferous, and Mr. Etheridge suggested in his paper that the beds in New South Wales in which the same fossil occurred should be classed as newer than Devonian. The question of the occurrence, or otherwise, of the fossil in the Brachiopod Sandstones, generally admitted to be Devonian, became therefore of some importance. It has been taken up by Prof. David, of Sydney University, and Mr. E. F. Pittman, A.R.S.M., Government Geologist, N.S.W., who worked together at Mr. Wilkinson's old section at Rydal; and by the writer, working at Glanmire, near Bathurst. At both localities specimens of *Lepidodendron* have been found associated with the Devonian brachiopoda; one of those obtained by the writer being actually attached to a cast of *Spirifer disjunctus*. Some other vegetable remains were found at the same place, but not sufficiently definite for classification. It appears therefore to be proved that *Lepidodendron* is Devonian in New South Wales, unless it can be shown that the Brachiopod Sandstones are Carboniferous.

With the exception of the Devonian rocks above described, there are apparently no rocks of that age within a radius of at least 20 miles, but the Brachiopod Sandstones are well known in many other parts of the colony. Nearly all the Devonian fossils occur as casts, but better-preserved specimens are found in the more shaly beds.

5. Rocks newer than the Devonian.

As already mentioned, the Devonian rocks are in places traversed by what appear to be dykes of felstone similar to some of those occurring in the Silurian. They are probably not much younger than the rocks which they traverse.

With the exception of these, no rocks younger than the Devonian are known in the district, until we come to the Tertiary drifts and the superincumbent basalt. Near Rydal, and at Lithgow, still farther east, the Devonian beds are overlain by Carboniferous rocks. About Lithgow one of the principal coal-fields of the colony is

[1] 'Geological and Palæontological Relations of the Coal- and Plant-bearing Beds of Palæozoic and Mesozoic Age in Eastern Australia and Tasmania,' by Ottokar Feistmantel, M.D., Mem. Geol. Surv. N.S.W., 1890, Department of Mines, Sydney.

[2] Prodr. Pal. Vict. 1874, dec. i. pl. ix.

[3] '*Lepidodendron australe*, M'Coy—Its Synonyms and Range in Eastern Australia.' Records Geol. Surv. N.S.W. vol. ii. pt. iii. pp. 119-133.

situated. The Coal Measures appear to belong to the upper series and are probably of Permian age, but beneath them is a series of sandstones and shales, considered to belong to the Lower Coal Measures, or Upper Marine series, of New South Wales, and to be of Middle or Upper Carboniferous age. These were found by Mr. Wilkinson to be quite unconformable to the Devonian beds. The exact limits of the Carboniferous rocks are scarcely known; but they do not appear to approach Bathurst, and it is doubtful whether they, or any Mesozoic beds, ever existed in the district.

6. The Later Tertiary Rocks.

In this neighbourhood there are several distinct beds of gravel. The highest, and no doubt the oldest, is situated west of the town, near the top of the Bald Hills. It is composed of well-rounded pebbles, made up almost entirely of quartz, which have evidently been rolled a considerable distance, since none of them are large; and it carries a little gold, but is not rich.

The basalt which caps the hills is about 200 feet thick. It is a moderately coarse-grained rock, containing numerous crystals of augite and olivine in a matrix which, under the microscope, is seen to be mainly made up of lath-shaped crystals of plagioclase-felspar. Microscopic sections present a remarkably fresh appearance, and sometimes show flow-structure very well. Some specimens show numerous white spots of calcite. When freshly broken the rock is of a bluish-black colour, and it is often columnar, the columns being about 12 to 18 inches in diameter, rather irregular in shape, from four- to seven-sided, five sides being perhaps the most usual. The columns show the usual transverse jointing, with occasionally the ball-and-socket arrangement at the ends, but this is not common. The rock makes first-rate road-metal. Mr. Curran[1] quotes an analysis by Mr. Mingaye, of the Mines Department, giving:—Silica 44·67 per cent., alumina 21·38, lime 10·24, magnesia 9·58, ferrous and ferric oxides 8·81. The writer's determination of the silica agrees fairly well with this. The specific gravity of several specimens gave a mean of 3·2.

Mr. Wilkinson was of opinion that the basalt came from Swatchfield, about 40 miles S.E. of Bathurst, near the head of the Fish and Campbell rivers. A specimen of basalt from Oberon, which is in that direction, is finer-grained than the Bathurst rock, but presents similar characters under the microscope; this confirms Mr. Wilkinson's opinion. There are, however, some indications that the basalt may have come from a different direction. The flow can be followed along the top of the Bald Hills for about 4 miles, to near the village of Perth, but there ceases abruptly, and there is no basalt known to the writer in the direction of Swatchfield for at least 20 miles. The trend of the flow is also rather away from that direction. At Blayney, 20 miles S.W., and Orange, 35 miles

[1] 'Geology and Petrography of Bathurst,' Proc. Linn. Soc. N.S.W., ser 2, vol. vi. (1891) p. 227; sep. cops. p. 57.

west, there is plenty of basalt, but this is of an entirely different character from the Bathurst rock, so that the latter is not likely to have come from either place. At a hill called Fitzgerald's Mount, about 14 miles west, the writer has found a basalt much resembling Bathurst basalt in microscopic characters; but further examination is necessary before one can speak with confidence on the subject of its identity or otherwise.

As to the age of the drift under the basalt little can be said. Diligent search has so far failed to reveal a single fossil, except some pieces of silicified wood, in that or any other Bathurst drift. It is about 400 feet above the level of the Macquarie River, and at the time it was deposited there was probably high ground over much of the present Bathurst Plains, so that it must have taken a long time to denude away so great a thickness of rock. The granite which underlies the drift is, as already mentioned, much decayed to a considerable depth from the surface, and this decayed granite is sometimes worn away very quickly, deep creeks being formed in the course of a few years.

It is, indeed, a characteristic of the country around Bathurst to find creeks from 10 to 20 feet deep, with vertical sides, and terminating abruptly at the head of the channel. These sometimes form a miniature river-system: there being a central channel with numerous tributaries, all running in cañons on a small scale.

The creeks are usually dry, except after heavy rain; but if in the past the rainfall was much greater than it is now, from 20 to 30 inches a year, the work of denudation may have gone on very rapidly.

The freshness of the basalt does not indicate a great age, and probably the oldest gravels are not older than the Pliocene period. The gravels next in age to that on the Bald Hills are at a much lower level, but of similar character, being formed of small quartz-pebbles, with beds of sand, and showing much false bedding. The later gravels, however, which form terraces roughly parallel to the Macquarie, are of different character, being much coarser and containing large pebbles, mainly of Devonian grits and felstones; they are very similar to the present river-gravel.

V. Summary.

The probable geological history of Bathurst, so far as at present known, may be thus briefly summarized:—The oldest sedimentary rocks of the district are Silurian. There was evidently an upheaval some time after the close of the Silurian period and before the Carboniferous: there may have been more than one such movement. The Silurian strata may possibly have been folded before the granite was erupted, as it is suggested those of Victoria were; but this is uncertain. In any case, the granite produced a zone of contact-metamorphism, while almost the whole of the Silurians may be considered to be examples of 'regional metamorphism'; but the agents producing changes in the rocks were most active south

of what is now Bathurst, and least so to the east, where the limestone is very little altered. The granite intrusion probably produced an anticlinal, and raised the area above the sea. After a time there was most likely a subsidence, but not at first a very great one, and the central area may not have been submerged, since the Devonian rocks, consisting of conglomerates, sandstones, and shelly limestones, with plant-remains, were probably deposited in a comparatively shallow sea. There must, however, have been a very great subsidence before the end of the period if, as Mr. Wilkinson states, the Devonian rocks are 10,000 feet thick at Rydal. Near Bathurst they have not been measured, but they do not appear to be so thick as that. They may have been reduced by denudation, but very possibly were originally thicker near Rydal than where they abut against the Silurian uplift in the Bathurst area.

It is uncertain whether the Devonian rocks belong to the Lower, Middle, or Upper division of the system, but at the close of the period there must have been a long interval during which both Silurian and Devonian strata were greatly denuded, and the granite exposed in places. This probably included the time when Lower Carboniferous rocks were being deposited in other parts of the colony. Then the Upper Carboniferous and Permian rocks were formed in the Lithgow district, but it is doubtful whether they ever extended to Bathurst.

What was the condition of the Bathurst area during the Mesozoic and early Tertiary periods there is no evidence to show. Just east of Lithgow, the Hawkesbury Sandstone (probably Triassic) occurs, of great thickness, and this very possibly once extended much nearer Bathurst than it does now. There is, however, a great gap in the geological history of the district until we come to late Tertiary times. We then find evidence that the streams ran over granite beds in much the same courses as they do now, but the country as a whole was probably a good deal more elevated than it is at present. Volcanoes burst out somewhere in the district, and there may have been several centres of eruption. Floods of lava were sent down the channels of the streams, sealing up the drifts under thick layers of basalt.

Since the volcanoes became extinct, subaerial denudation has gone on steadily. All the high ground around the streams has been swept away, the materials going to increase the great deposits of drift-earth far to the west. Most of the basalt has also gone, only the outliers on the Bald Hills, and on a few other small hills in the neighbourhood, remaining to indicate the course of the old river-channel, now become a hill. As the stream or streams shifted their course and cut their channels deeper, they left terraces of gravel to mark the successive heights at which they flowed.

There is a popular tradition that the Bathurst Plains were formerly covered by a lake, but there does not seem to be any evidence in support of this. No doubt, in wet years, much of the low ground around the channel of the Macquarie, and between the low hills, may have been covered by water for some time. By the

general testimony of old inhabitants, the channel of the river has become both wider and deeper during the last twenty or thirty years, its capacity for carrying off flood-waters has thereby been increased, and extensive floods have become rarer. The channel may once have been very shallow, so that wide stretches of country would be temporarily covered with water, giving it the appearance of a lake, and thus accounting for the tradition.

Discussion.

The President said that the paper dealt with a comparatively unknown district, and it appeared to contain many important facts. He thought that the Author had not clearly connected the metamorphic with the Upper Silurian rocks. There was evidently a great hiatus between the *Pentamerus Knightii*-limestone and the overlying, so-called Devonian.

The Rev. H. H. Winwood and Mr. J. E. Marr also spoke.

10. *On the* Stratigraphical, Lithological, *and* Palæontological Features *of the* Gosau Beds *of the* Gosau District, *in the* Austrian Salzkammergut. By Herbert Kynaston, Esq., B.A., Scholar of King's College, Cambridge. (Communicated by J. E. Marr, Esq., M.A., F.R.S., Sec.G.S. Read December 20th, 1893.)

Contents.

I. Introduction.

§ 1. *Prefatory Remarks.*

During the latter part of the summer of 1892, I was enabled by means of a grant from the Worts Fund (Cambridge University) to do some geological work in the Eastern Alps. My observations during the seven weeks or so that I spent on the Continent were confined to the Upper Triassic and Upper Cretaceous rocks of the neighbourhood of Aussee, Altaussee, Hallstatt, and Gosau, in the Austrian Salzkammergut, and more especially to the Cretaceous rocks of Gosau; and it is the remarkable formation here developed that I propose to deal with in this paper.

I am aware that the subject of the Gosau Beds is by no means a new one, and that many eminent stratigraphists and palæontologists, whose researches have brought forth a copious literature and much discussion, have been before me in the same field. With the exception, however, of the remarkable researches of Murchison and Sedgwick, little, if any, detailed work has been done on these beds by English geologists. Furthermore, although the formation at Gosau and other places in the Eastern Alps has been known for a long time, yet its isolated position, peculiar stratigraphical relations, and unique fauna have always been subjects of much discussion amongst European geologists, and the question of the exact geological horizon of the beds and their palæontological relations cannot even yet be said to have been definitely settled.

It is proposed, therefore, in the following pages to give a summary of the results of the principal previous investigations on the stratigraphy and palæontology of the Gosau Beds, to give a full account of my own observations and subsequent palæontological work, to

compare my observations with the views of other workers, to discuss from the results that I have obtained the geological horizon of the beds, and to endeavour to point out their probable English equivalents.

§ 2. *Bibliography.*

In dealing with the literature of the Gosau Beds, I have not referred to accounts published before the classic memoir of Sedgwick and Murchison. These illustrious pioneers of geology visited the Gosau district in the year 1829, and the results of their investigations appeared in a series of papers on the Eastern Alps, which were read before the Geological Society of London at various meetings during the years 1829, 1830, and 1831, and these were finally rearranged and published as a separate memoir, entitled 'On the Structure of the Eastern Alps,' in the 'Transactions' of the Society (2nd ser. vol. iii. pt. ii.) in 1832. Before the year 1829 the Gosau district had been described in a more or less general manner by Keferstein ('Geologie von Teutschland,' vol. v. 1827) and Lill von Lilienbach. The memoir, however, of Sedgwick and Murchison was the first account of any importance. Their views were immediately opposed by Ami Boué, who had studied the Gosau Beds near Wiener Neustadt in 1822. These he had taken for Jurassic, but later he classed them as Lower Greensand, in opposition to the views of Murchison and Sedgwick, who maintained that they represented passage-beds between the uppermost Cretaceous and the lowermost Tertiary deposits; in fact their whole memoir was a gallant attempt to bridge over with the Gosau Beds the great gap between the Secondary and Tertiary systems of Europe.

Even in 1843 we find Klipstein upholding the Tertiary age of these beds, and, while recognizing the Cretaceous character of the fossils which they contain, he accounted for their presence by supposing that they were simply derived from an older Cretaceous formation, which had been entirely destroyed during the deposition of the Gosau Beds. Then followed various papers and memoirs by Cžjžek, Peters, Zekeli, Reuss, Fr. von Hauer, Stoliczka, Zittel, and others. I append a list of all the references to, and descriptions of, the Gosau Beds and their organic remains, that I have been able to find, as having appeared since the year 1832. The rich series of organic remains from Gosau and other places have been described by Zekeli, Reuss, Stoliczka, Zittel, Fr. von Hauer, and H. G. Seeley, and the descriptions of some of these authors have enabled me to identify a large number of the fossils which I collected from these beds.

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1865. STOLICZKA, Dr. FERD.—'Eine Revision der Gastropoden der Gosauschichten in den Ostalpen.' Sitzungsber. d. kaiserl. Akad. Wissensch. Wien, vol. lii. pt. i. p. 104.

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§ 3. *Situation and Physical Aspects of the Gosau Valley.*

The Gosau Valley is situated in the south of Upper Austria, close to the borders of Styria, and in the heart of the Salzkammergut. It forms almost a complete semicircle to the west and south-west of the Lake of Hallstatt.

The waters of the Gosau Bach have their origin in the glacier-fed streams of the western slopes of the Dachstein, which rises to a height of over 10,000 feet above the sea-level. These streams plunge into the Hinterer Gosau See, a small lake about ½ mile long, and thence descend somewhat steeply to the Vorderer Gosau See, in a northwesterly direction, receiving on their way the mountain-torrents of the Donnerkögl. From the foot of this lake, which is about 1 mile long and ¼ mile broad, the stream keeps a general northerly course, sometimes trending slightly to the east, until it reaches Gosau village, about 5 miles from the Vorderer See, when it gradually sweeps round to the east, and maintains this course down the narrow gorge of the Gosauzwang until it finally mingles with the waters of Hallstatt Lake at Gosau Mühle.

The Gosauthal proper consists of that broad, open, cultivated, portion in which the village of Gosau lies, and which extends approximately from Gosau Schmidt on the south to Klaushof, a couple of miles or so E.N.E. of Gosau village. The whole of this valley thus forms one of the main lines of drainage on the northern slopes of the Dachstein massif; another well-marked line of drainage being formed by the Wald Bach, which flows E.N.E. from the Hallstatt glacier.

It is not difficult to see that the physical characteristics of this valley are due to its peculiar geological structure. Thus the steeper and bolder portions, both in the neighbourhood of the Gosau lakes and in the Gosauzwang, consist of hard, compact, crystalline limestones, much folded and disturbed, belonging to the Upper Triassic Dachsteinkalk and Wettersteinkalk, the latter of which constitutes the jagged chain of peaks of the Donnerkögl, reminding one of the dolomite mountains of the Tyrol; while the former builds up the greater part of the Dachstein group and most of the higher mountains round the Lake of Hallstatt. But in that portion of the valley which constitutes the Gosauthal proper there is a broad, more or less basin-shaped, depression in the Alpine limestone. It is in this that we find the considerably younger and less disturbed Gosau Beds; and, as one would expect, they consist of much softer material, chiefly thick beds of marl, alternating with sandstones, shales, and conglomerates. Hence the decreased height and gentler slope of the flanking mountains, the broad pasture-lands and generally tamer aspect of the valley.

II. Distribution of the Beds: Stratigraphy of the Gosau District, and Comparison with other Areas.

The Gosau Beds, while they may be said to be typically developed in the Gosau Valley, have on the whole a fairly extensive distribu-

tion in the Eastern Alps, and chiefly on the northern flanks of the chain. They nearly always occur in basin-shaped or trough-shaped areas in the Alpine limestone, similar to that of which the Gosauthal may be taken as a fair type, or in small, narrow, high-lying valleys, resembling that of Zlam, near Aussee, in Styria. As before mentioned, they generally flank the northern zone of Alpine limestone (Kalkalpenzone), with, however, the exception of the one locality of Obersiegsdorf,[1] south-east of the Chiem See in Bavaria; but they never encroach on the central axial portion of the chain.

Everywhere they occur in the form of isolated outliers, resting unconformably on the older Alpine Trias, and they are never associated with either younger or older Cretaceous beds, with one exception, namely near Ruhpolting[1] in Bavaria, west of Salzburg, where they are exposed resting on beds of the age of the Gault. The beds of the Gosauthal are not confined to that valley, but, constituting as they do the whole of the hills on its western side, from the Zwiesel Alp on the south to the southern slopes of the Russberg on the north, they are continued into the adjoining valley of Russbach as far west as a mile or so south-west of Russbachsag, and they also extend up the tributary valley of the Randoa Bach as far as Neue Alp, between the Gamsfeld and the Hohe Platten. Farther west they are again seen in the neighbourhood of Abtenau, at the Untersberg, and at other places in the neighbourhood of Salzburg.

West of Salzburg the Gosau Beds occur at Urschlauer Achen, near Ruhpolting, Obersiegsdorf, and other localities in the south of Bavaria. In the Tyrol they have been described by Pichler[2] in the Brandenberger Thal.

North of the Gosau Valley we find the Gosau Beds in the basin of St. Wolfgang, which commences at St. Gilgen and extends as far as Ischl: this locality has been described by Dr. A. E. Reuss.[3] Probably one of the most important and best known localities for the Gosau Beds is that of Neue Welt, near Wiener Neustadt, south of Vienna, where they occur in a typical basin in the older Alpine limestones, in the neighbourhood of the villages of Piesting, Grünbach, Dreistätten, and Müthmannsdorf. The strata here exposed have been well described by Sedgwick and Murchison,[4] Cžjžek,[5] and Zittel.[6] Other localities are the Gamsthal, near Hieflau, in Styria, described by Peters[7] and Redtenbacher,[8] and that of Zlam, near Aussee (also in Styria), described by Peters,[7] and more briefly by Sedgwick and Murchison.[4]

More recently a new locality for the Gosau Beds has been de-

[1] Zittel, Denkschrift. d. kaiserl. Akad. Wissensch. Wien, vol. xxv. (1866) p. 162.
[2] Jahrb. d. k. k. geol. Reichstanst. vol. vii. (1856) p. 735.
[3] 'Beiträge zur Charakteristik der Kreideschichten in den Ostalpen,' Denkschrift. d. kaiserl. Akad. Wissensch. Wien, vol. vii. (1854) p. 1.
[4] Trans. Geol. Soc. ser. 2, vol. iii. pt. ii. (1832) p. 364.
[5] Jahrb. d. k. k. geol. Reichsanst. vol. ii. (1851) p. 144.
[6] Denkschrift. d. kaiserl. Akad. Wissensch. Wien, vol. xxv. (1866) p. 160.
[7] Abhandl. d. k. k. geol. Reichsanst. vol. i. (1852) pt. i.
[8] Jahrb. d. k. k. geol. Reichsanst. vol. xxiv. (1874) pp. 1–6.

scribed in Transylvania by Maurice de Tribolet.[1] That author describes a collection of fossils from Monorostia, on the Maros, which occur as impressions in a reddish ferruginous sandstone, and from which 24 species of Gosau forms have been determined. Several other localities for various beds of the same age are also known in South-eastern Hungary, in Southern and Western Transylvania, etc.;[2] but these, of course, do not come within the province of the Eastern Alps.

Returning now to the Gosau Valley, we find that it is comparatively easy to establish the boundary-line between the Gosau Beds and the older Triassic limestones, upon which they rest everywhere with a marked unconformity. I do not know of any spot in the Gosauthal or in the Russbachthal where this unconformable junction is actually exposed to view, but everywhere the stratigraphical evidences of it are too clear for one to mistake their significance. As a rule the older Triassic limestones tower up above the younger Gosau Beds as steep mountain-slopes or almost perpendicular precipices, so that the actual boundary-line between the two is almost always covered over by talus. In the Gosauthal proper we find the younger beds extending from near Gosau Schmidt on the south to the foot of the Bärn Bach on the north. On the eastern side of the valley they form the lower slopes of the Ressenberg and part of its summit, while on the western side they constitute the whole range of mountains from the Zwiesel Alp to the lower slopes of the Russberg and the Hohe Platten, the highest in the range being the Hornspitze, about 5000 feet above sea-level. They are continued westward into the Russbachthal as far as Heugut, and stretch up the tributary valley of the Randoa Bach on the north as far as Neue Alp. The total area occupied by the beds would probably not average much less than 30 square miles.

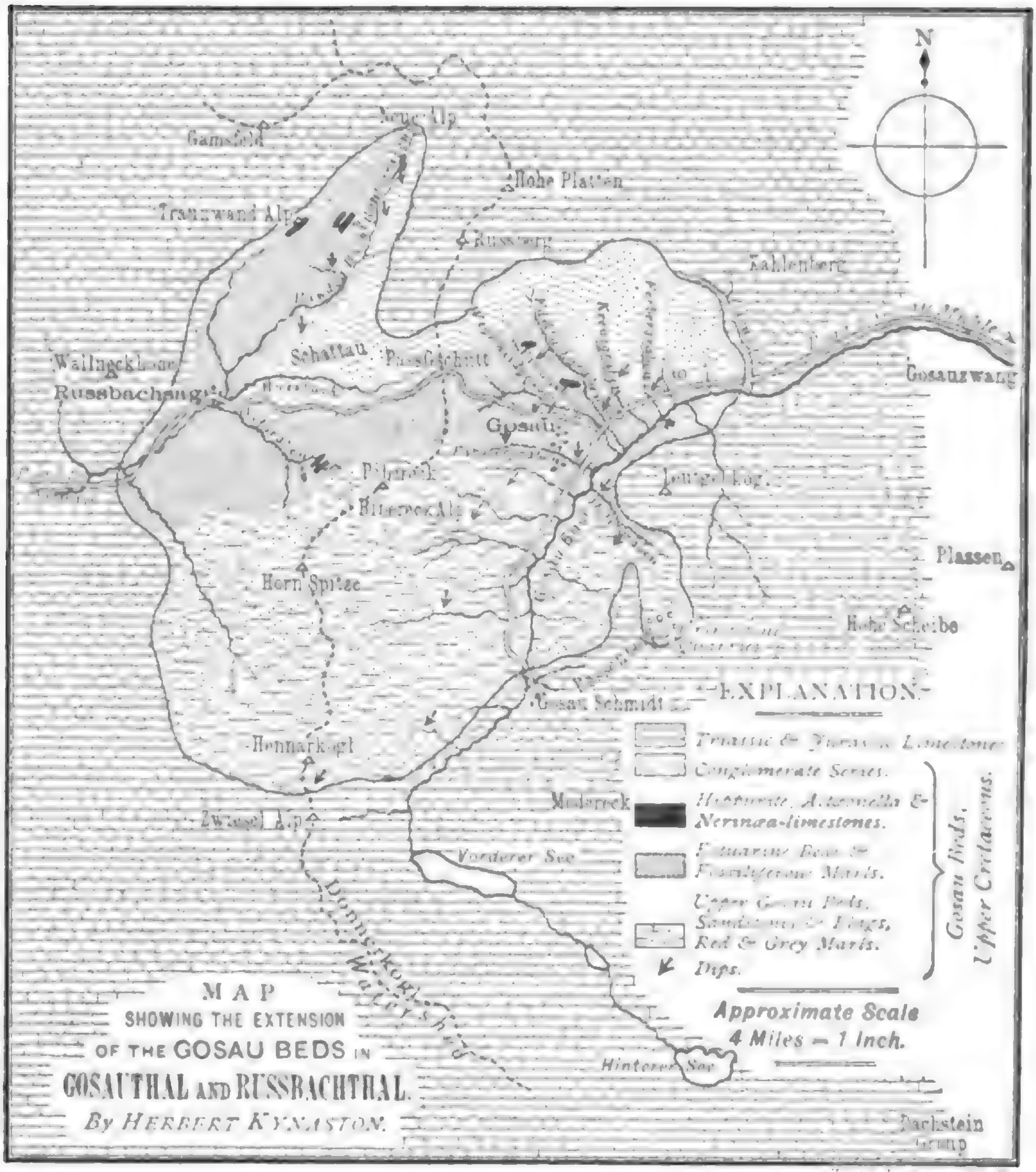
The Map which is included in this section illustrates the distribution of the Gosau Beds in the Gosauthal and the Russbachthal. It is based on the Austrian Ordnance Survey Map (Zone 15, Col. ix. Ischl & Hallstatt—scale 1 : 75,000), on a copy of which I marked in from my own observations the extent of the beds and the nature of the principal strata in the different parts of the district. A geologically-coloured map of this district was published with Reuss's memoir on the Gosau Beds (Denkschrift. Akad. Wien, vol. vii. 1854), but I had not seen this until my own was completed. My own map will be seen to agree with Reuss's in the main, but to differ in several smaller, though not unimportant points, chiefly with respect to the boundary-line between the Gosau series and the older Alpine limestones. (For Map, see p. 126.)

By far the best series of natural exposures of the beds are found on the sides of the peculiar ravines or gullies (*gräben*), in which the mountain-streams are confined, and which are so characteristic of the district. Often, however, as in the lower part of the Wegscheid-

[1] Neues Jahrb. 1875, pp. 52, 53. Noticed in Geol. Record for 1875, p. 104.

[2] Fr. von Hauer, 'Die Geologie der österr.-ungar. Monarchie,' 1878, pp. 534 and 536–538.

graben, scarcely anything can be seen of the actual beds *in situ*, the steep sides of the ravine consisting of disintegrated shale and marl in an almost soil-like condition, throughout which the various characteristic fossils are loosely scattered, though generally merely as casts or in a more or less fragmentary condition. This is usually the case when the slope of the sides of the ravine is gentle enough to allow of the disintegrated material of the rock resting upon them,



and with this are mingled soil and plant-remains from above, boulders, pebbles, and innumerable shells of land-molluscs. Great masses of soil and rock may sometimes slip down from the upper part of the banks, bringing with them trees and shrubs, and in this way a portion of the ravine may in process of time become inextricably choked up by a confused mass of the trunks and branches of dead fir-trees, masses of soil, boulders, and disintegrated marl, the

whole forming by no means a pleasing prospect from the point of view of the stratigraphical geologist.

North and north-west of Gosau village there are a large number of these ravines, no less than eight having been carved in the sides of the mountain between the road going over the Gschütt Pass to Abtenau and the eastern boundary of the Gosau Beds. Of these, going from east to west, the principal are the ravines of Bärn Bach (or Bärengraben [1]), Ferbergraben, Kreuzgraben, Edelbachgraben, and Wegscheidgraben. Along the lower portion of the Bärn Bach steep slopes and perpendicular faces of Triassic limestone (Dachsteinkalk) come abruptly down for some distance along the eastern side. Along the western side I did not find any rock *in situ*, but the steep and roughly-terraced banks consist of soil, gravel, and large boulders, probably morainic material. Possibly, if time had allowed, exposures of the basement conglomerate-series might have been found higher up the ravine.

In the three next successive ravines to the west, including Ferbergraben, nothing is seen except very coarse conglomerates. The bedding is so massive that it is often extremely difficult to make out the stratification. The dip, where seen, is in a general south-westerly direction, and varies in inclination from about 30° to 50°. The conglomerate consists chiefly of large pebbles, sometimes boulders of about 1 foot in diameter, of different varieties of crystalline limestone; they are generally well-rounded, though more or less angular, schistose-looking fragments sometimes occur. Quartz-pebbles are not very common; the matrix is calcareous, and generally very hard and compact, of a greyish colour, or sometimes reddish from the presence of iron oxide. This coarse conglomerate is found almost right up to the head of the Ferbergraben, here and there alternating with bands of reddish grit and sandstone. Near the head of the stream the conglomerate alternates with beds of bluish marlstone, sometimes containing a few badly-preserved fossils. Still higher up the side of the hill, the beds appear to abut against a steep wall of Dachsteinkalk running almost N.E. and S.W., and forming the conspicuous scars of the Hohe Platten and the Russberg.

Passing westwards to the Kreuzgraben, we find at the foot of the ravine, close to a chalet, similar conglomerates alternating with soft reddish marls; but farther up the gully only conglomerate is exposed. Probably we have here the passage from the coarse conglomerate-system to that of the fossiliferous marls, so well exposed in the ravines farther west. The conglomerate-system is certainly more massively developed in this neighbourhood than in any other part of the Gosauthal or the Russbachthal, and its thickness probably amounts to nearly 300 feet.

In the Edelbachgraben, the next ravine of any importance to the west, one is at once struck by the complete absence of conglomerate. We find, however, a thick series of bluish-grey marls and shales, with here and there a band of tough bluish-grey sandstone, dipping

[1] Reuss, Denkschrift. d. kaiserl. Akad. Wissensch. Wien, vol. vii. (1854) p. 6.

at an angle of about 20° in a general S.S.W. direction. These marly and shaly beds may be followed some way up the ravine, and are probably more than 100 feet in thickness at this locality. A large number and variety of fossils characterize these beds, such, for instance, as: *Montlivaltia rudis* (E. & H.), *Cyclolites hemisphærica* (Lam.), *Plicatula aspera* (Sow.), *Neithea quadricostata* (Sow.), *Cardium productum* (Sow.), *Nerinæa flexuosa* (Sow.), *Ampullina bulbiformis* (Sow.), *Turbo decoratus* (Zek.), *Aporrhais costata* (Sow.), *Cerithium reticosum* (Sow.), and many others.

A little farther west, at Schrickpalfen, on the sides of the hill, we find conglomerate overlain by Hippurite- and Coralline-limestones, and these again by marls. *Hippurites cornu-vaccinum* and *H. organisans* occur, and several reef-building species of corals. Above the limestones we find marls similar to those of the Edelbachgraben, and containing similar fossils. These marls again occur farther west in the Wegscheidgraben, close to the road leading from Gosau village over the Gschütt Pass to Abtenau.

Passing over into the Russbachthal, one finds the lower portion of the Gosau Beds well exposed throughout the greater part of the tributary valley of the Randoa Bach, with a similar succession to that already observed in the *gräben* north of Gosau village. On the slopes of the Traunwand, near the Alpenhütte, we find calcareous conglomerate overlain by Hippurite-limestone, consisting of large individuals of *Hipp. cornu-vaccinum*, numerous corals, and a few brachiopoda, while a little lower are calcareous marls, crowded with *Actæonella conica*, *Cerithium Simonyi*, *Volvulina lævis*, etc. Conspicuous banks of Hippurite-limestone again occur above the Stöcklwaldgraben, close to a chalet, and are doubtless on the same horizon as those on the Traunwand Alp.

A good section, showing beds low down in the fossiliferous series, is exposed in the bed of a small stream entering the Randoa Bach, a short distance above the last-named locality of the Stöcklwaldgraben. Alternations of conglomerates, sandstones, shales, and marlstones are seen, with many fossils in some of the marlstones, such as *Pinna cretacea* (Schl.), *Cypricardia testacea* (Zitt.), *Panopæa frequens* (Zitt.), and *Nerinæa gracilis* (Zek.). Sometimes blocks of marlstone consisting almost entirely of *Volvulina lævis* may be extracted. *Actæonella gigantea* (Sow.) and *Nerinæa Buchi* (Kefst.) also occur, and a few corals.

The Hippurite-limestone is of more or less local occurrence and does not always crop out immediately above the basement-conglomerate, although that is invariably its position whenever it does occur; so sometimes we may get the conglomerate-system passing gradually up into the marl-system without the intervention of any limestones.

The *Nerinæa*-limestone is well exposed in the bed of the stream a short way below the Neue Alp. It occurs as a conspicuous mass of compact grey limestone, about 6 feet in thickness, and containing in places crowds of *Nerinæa nobilis*, usually arranged in bands. Above this, we notice, a little farther on, bluish sandstones and marls;

these are probably part of the brackish-water or estuarine beds, which on the east side of the stream at the Neue Alp have been worked for coal. They consist for the most part of soft, pale grey marls with thin layers of a bituminous coal, and containing brackish-water shells, such as *Melania granluatocincta* (Stöl.) and *Tanalia Pichleri* (Hörn.), both of which are extremely common. The gasteropoda from these beds have been described by Stoliczka,[1] and a few lamellibranchs by Zittel.[2] They belong to a mixture of land, freshwater, and marine forms, so that the beds are probably of brackish-water origin, and were most likely deposited in an estuary.

The boundary-line of the Gosau Beds in this neighbourhood seems to curve sharply round to the north of the Neue Alp, so that in this valley we have a long tongue-like extension of these beds, gradually tapering off towards the head of the stream.

On the south side of the Russbachthal there are good exposures at the Nefgraben, a deep, tortuous ravine on the north-western slopes of the Hornspitze. A thick series of dark grey marls, here and there alternating with shales and sandstones, is exposed, with two bands of limestone towards its upper portion containing *Hippurites* and numerous reef-building and other forms of corals. A larger and more varied series of corals may be collected here than in any other locality in the Gosau district. The whole series of beds here exposed probably amounts to almost 1000 feet in thickness; the general dip is rather east of south, and the angle varies considerably. The following are some of the commoner forms occurring here:—

Actinozoa.

Agathelia asperella (Reuss).
Trochosmilia complanata (E. & H.).
Diplocterium lunatum (Mich.).
Rhipidogyra undulata (Reuss).
Astrocœnia magnifica (Reuss).
" *ramosa* (E. & H.).
" *reticulata* (E. & H.).
Montlivaltia rudis (E. & H.).
Calamophyllia multicincta (Reuss).
Hydnophora styriaca (E. & H.).
Thamnastræa, several sp.
Cyclolites macrostoma (Reuss).
" *elliptica* (Lam.).
" *hemisphærica* (Lam.).

Lamellibranchiata.

Hippurites cornu-vaccinum (Bronn).
Hippurites organisans.
Plagioptychus Aguilloni (d'Orb.).
Janira (*Neithea*) *quadricostata* (Sow.).
Panopæa frequens (Zitt.).
Cypricardia testacea (Zitt.).
Cardium productum (Sow.).

Gasteropoda.

Volvulina lævis (d'Orb.).
Ampullina (*Natica*) *bulbiformis* (Sow.).
Natica lyrata (Sow.).
Aporrhais costata (Sow.).
Cerithium reticosum (Sow.), etc.

Returning to the western side of the Gosauthal, we find good exposures of the fossiliferous marls in the Finstergraben, a small ravine immediately south-west of Gosau village. The beds resemble those of the Edelbachgraben, already described, but are higher in the series,

[1] Sitzungsber. d. kaiserl. Akad. Wissensch. Wien, vol. xxxviii. (1859) p. 482.
[2] Denkschrift. d. kaiserl. Akad. Wissensch. Wien, vol. xxv. (1866) pt. ii. p. 77.

and, as they are traced up towards the upper part of the ravine, they become more sandy, while the fossils gradually disappear. Thus the upper slopes of the Bibereck, above the ravine, consist of tough bluish sandstones, alternating with sandy micaceous shales and flags, and containing scarcely any organic remains. In the lower part of the Finstergraben *Crassatella macrodonta* (Sow.) and *Cucullæa chiemiensis* (Gümb.) are very characteristic, besides the other commoner forms; also *Aporrhais* (*Alaria*) *costata* (Sow.) and *Malaptera* (*Pterocerus*) *Haueri* (Zek.).

Farther south-west a fairly deep *graben* leads up to the Bibereck Alp, and in this we find the unfossiliferous beds, seen above the Finstergraben, well exposed. Alternations of shale with flaggy micaceous beds and bands of tough bluish sandstone are frequent, while the only organic remains are obscure vegetable-fragments, and worm-tracks on the surface of the flaggy and sandy beds. These beds are evidently of a very shallow-water character, but when traced up on to the Bibereck Alp and on to the upper slopes of the Hornspitze, gradually a slightly deeper-water type of deposit is found to predominate, and the sandstones, flags, and sandy shales give place to greyish, red, variegated, fine-grained, and tough marls. Just above the Bibereck Alp this marl system is exposed in a fine cliff-section, which must be at least 300 feet in height; it forms another cliff just below the top of the Hornspitze, on its eastern side, and is exposed in numerous ravines and gullies in the hills between the Finstergraben and the Zwiesel Alp.

On the eastern side of the valley the Gosau Beds occupy a much smaller area than they do on the western side. The fossiliferous marls are well exposed in the Hofergraben, almost immediately opposite Gosau village. The succession here resembles on the whole that of the Finstergraben, and is probably on the same horizon. Here also the fossiliferous marls and shales gradually pass up into a series of bluish-grey sandstones and sandy micaceous shales, with worm-tracks and ripple-marks. Similar beds are also found in the various small ravines, which cut into the sides of the hills between the Hofergraben and Gosau Schmidt. Close to the top of the Ressenberg thick beds of the bluish-grey sandstone predominate, and are quarried at the Schleifsteinbrüche for whetstones and grindstones.[1] Apparently the great system of grey and red marls of the Hornspitze, the Hennarkögl, and the Zwiesel Alp is not present on the eastern side of the valley, though the sandstone-and-sandy shale system, with worm-tracks and ripple-marks, is better developed on this side, and possibly its upper portion may represent part of the red-and-grey marl series.

We are now in a position to construct a complete classificatory table of the Gosau series as exposed in the Gosauthal and the Russ-

[1] Sedgwick and Murchison, Trans. Geol. Soc. 2nd ser. vol. iii. pt. ii. (1832) p. 358; Reuss, Denkschrift. d. kaiserl. Akad. Wissensch. Wien, vol. vii. (1854) pp. 27, 28.

bachthal. We have traced the beds in ascending sequence from the northern portion of the district to the southern, and have noted their variations in lithological characters and the principal organic remains characterizing the different series.

The average dip of the strata is south, varying from almost horizontal up to an angle of about 50°. The beds of the Russbachthal are more disturbed than those of the Gosauthal. The total thickness of the group probably does not fall far short of 3000 feet, the Hornspitze, which is about the highest mountain flanking the western side of the valley, being a little over 2000 feet above the level of Gosau village, and it consists chiefly of the massive upper unfossiliferous series.

Sedgwick and Murchison[1] divided up the series into six principal systems, as follows, in ascending order:—

1. Coarse conglomerate-system; maximum thickness 200 to 300 feet.
2. Arenaceous limestone or calc-grit, here and there in strong bands, alternating with beds of pebbles and great masses of marl; very fossiliferous. Thickness about 150 feet.
3. A great system of blue marls, here and there with bands of indurated marl, calc-grit, or sandstone, and abounding in well-preserved organic remains.
4. Alternations of marls, sandy marls, and sandstones, with obscure traces of plant-remains (best exposed on the sides of the Ressenberg).
5. Greenish, grey, micaceous, thin-bedded sandstone. Portions well exposed near the top of the Ressenberg. Several hundred feet.
6. Red, slaty, micaceous sandstone, alternating with greenish and reddish sandy marls. Partly on the same parallel with the preceding, and partly higher. 500 feet.

Reuss's classification[2] is as follows:—

LOWER	1. Basement conglomerate. 2. Fossiliferous bluish-grey marls, interstratified with limestones containing *Hippurites*, *Actæonella*, *Nerinæa*, and corals, with sandstones and conglomerates.
UPPER	3. Grey and red, indurated, unfossiliferous marls, sometimes alternating with sandstone and conglomerate. 4. Calcareous fine-grained sandstones, with grey micaceous marls; unfossiliferous.

Zittel also divides the Gosau Beds into four main divisions,[3] in ascending order, as follows:—

1. Conglomerate and Hippuritenkalk with *Hipp. cornu-vaccinum*.
   Actæonellenkalk with gasteropods.
   Nerineenkalk.
2. Freshwater beds of the Neue Alp; shales with coal.
3. Soft grey marls with corals, bivalves, gasteropods, hippurites (*H. organisans*), and *Caprina*.
4. Grey and red, hard, unfossiliferous marls, alternating with sandstones and conglomerates, fine-grained sandstones, and grey micaceous marls.

It will be noticed that both Sedgwick & Murchison and Reuss

[1] *Op. supra cit.* pp. 355–358.
[2] *Op. supra cit.* p. 35.
[3] Denkschrift. d. kaiserl. Akad. Wissensch. Wien, vol. xxv. (1866) pt. ii. p. 173.

omit any mention of the estuarine beds with coal at the Neue Alp, while Zittel makes them constitute a separate division.

Sedgwick and Murchison completely mistook the position of the lower Hippurite-limestone, regarding it as resting immediately against the Triassic limestones, and belonging altogether to an older series of Secondary deposits, but not to the Gosau Beds at all, although they recognized two species of *Hippurites* in their lower fossiliferous series (No. 2). Zittel, on the other hand, takes the correct view of the position of the two Hippurite-limestones, but hardly seems to give due importance to the sandstone-and-sandy shale series, so well developed on the Ressenberg, and he seems rather to confuse it with the succeeding group of red and grey marls. It seems to me that quite as much prominence should be given to each of these two systems as to that of the fossiliferous marls, although, of course, the latter are more important from a palæontological point of view.

Sedgwick and Murchison split up the fossiliferous marls into two portions on palæontological grounds (*op. jam cit.* p. 357). There is certainly, however, no stratigraphical line of demarcation in the series; nor do subsequent investigations seem to have confirmed the existence of so much distinction, palæontologically, between the upper and lower portions as those authors considered they had grounds for establishing. Hence, it would seem more convenient to retain the fossiliferous marly beds in one group.

Bearing in mind these considerations, and also the results of my own observations, I have adopted the following classification of the Gosau Beds of the Gosauthal and the Russbachthal. For the sake of convenience we may divide them into a lower group, which is extremely fossiliferous, and an upper group, which is almost entirely devoid of organic remains.

The beds are arranged in ascending order :—

LOWER GOSAU BEDS.	1.	*a.* Coarse conglomerate, sometimes alternating with grits, sandstones, and marls (Ferbergraben, etc.). *b.* Limestone with *Hipp. cornu-vaccinum* (Traunwand, etc.). *c.* Do. *Actæonella conica*, etc. (Traunwand, etc.). *d.* Do. *Nerinæa* (Traunwand, Neue Alp).
	2.	Estuarine series of the Neue Alp.
	3.	Bluish-grey marls, with some limestone; very fossiliferous. *Hippurites organisans*, reef-building corals, *Trochosmilia*, *Cyclolites*, *Panopæa*, *Cypricardia*, *Janira*, *Cardium*, *Cucullæa*, *Crassatella*, etc. *Ampullina bulbiformis*, *Cerithium*, *Aporrhais*, *Fusus*, *Nerinæa*, etc.
UPPER GOSAU BEDS.	4.	Grey sandstones and flags, with some sandy shales, with obscure plant-remains, worm-tracks, and ripple-marks. Well seen on the sides of the Ressenberg and below the Bibereck Alp.
	5.	Grey, red, and variegated sandy marls, here and there, especially towards the upper part, alternating with sandstones, grits, and conglomerates. Well seen on the sides of the Hornspitze, Hennarkögl, and Zwiesel Alp.

Comparing the Gosau Beds of the Gosauthal and the Russbachthal with those of other localities in the Eastern Alps, it will be seen that some of the beds are variable or merely of local importance, while

others are constant. Certainly some are of rather variable occurrence in one and the same area; thus both the *Actæonella*- and *Nerinæa*-limestones are absent in the Nefgraben. Hippurite-limestones, of which in different localities there may be one, two, or three, are very poorly developed in the Gosauthal compared with their development in the Russbachthal, while the Estuarine Beds are altogether absent in the Gosau Valley.

At Neue Welt, near Wiener Neustadt, a locality which has been described by Zittel and others,[1] we find a Hippurite-limestone between the *Actæonella*- and *Nerinæa*-limestones. The Estuarine series is much better developed here than at the Neue Alp; it contains workable coal-seams, with numerous plant-remains, freshwater shells, and marine fossils in isolated beds, such as *Omphalia*, *Astarte*, *Circe*, *Turbo*, etc., and reptilian remains, which latter have been described by Bunzel and Seeley. Above the Estuarine series comes limestone with *Actæonella* and other gasteropoda. The fossiliferous marls are probably better developed at Gosau. Above this series we see at Neue Welt what Zittel calls '? Orbitulitensandstein,' but with regard to this horizon Suess remarks, "in some places rose-coloured limestone-beds with *Orbitoides* and the remains of a small decapod are seen, which seem to succeed directly this zone" (*i. e.* the fossiliferous marls).[2] There are certainly no beds with *Orbitulites* at Gosau. The next highest beds are the *Inoceramus*-marls, the exact position of which in the series at Gosau is uncertain. They may correspond to the upper portion of the fossiliferous marls, where *Inoceramus Cripsi* is so common (namely, in the Hofergraben), or possibly to some portion of the unfossiliferous group. The former seems more likely to be the case.

In the Gamsthal, near Hieflau, in Styria, described by Peters[3] and Redtenbacher,[4] there is no Hippurite-limestone with *H. cornu-vaccinum* seen immediately above the basement conglomerate. Possibly, however, it is present here, but is not exposed. Above the conglomerate, we find here *Nerinæa*-limestone, followed by freshwater beds with coal; then sandstones come on, followed by *Actæonella*-limestone and Hippurite-limestone; then sandstones passing into massive fossiliferous marls, on the same horizon as the fossiliferous marls of Gosau; and finally Orbitulite-beds, corresponding with those of Neue Welt.

In the Zlam Valley, near Aussee, the basement-conglomerate system is very thick, and is followed by a series of marls, with some limestones. This locality is described by Sedgwick and Murchison[5] and Peters.[6]

[1] Zittel, Denkschrift. d. kaiserl. Akad. Wissensch. Wien, vol. xxv. (1866) pt. ii. pp. 160 *et seqq.*

[2] Note to Seeley's paper 'On the Reptile Fauna of the Gosau Beds,' Quart. Journ. Geol. Soc. vol. xxxvii. (1881) p. 703.

[3] Abhandl. d. k. k. geol. Reichsanst. vol. i. (1852) pt. i.

[4] Jahrb. d. k. k. geol. Reichsanst. vol. xxiv. (1874) pt. i. pp. 1–6.

[5] Trans. Geol. Soc. 2nd ser. vol. iii. pt. ii. (1832) p. 362.

[6] *Op. supra cit.*

The upper unfossiliferous series seems to be more extensively and massively developed in the Gosau district than in any other locality.

Thus, on the whole, the Gosau Beds of the Gosau Valley correspond very well with those of Neue Welt, Gamsthal, and Zlam, and in the same way it might be shown that they correspond with those of St. Wolfgang and other areas. In short, the Gosau Beds might be briefly described as a series of conglomerates, sandstones, and marls, of varying thickness, constituting a complete formation with a peculiar and at the same time extremely rich and varied fauna, occurring in isolated trough-shaped areas in the Upper Triassic and Rhætic limestones of the Eastern Alps. In the lower part of the series, at the margins of the trough-shaped areas, are the most varied alternations of rock, and also the greatest abundance of organic remains, while in the upper part of the series, at least n the Gosau district, the rocks are monotonous and barren.

III. Palæontology of the Gosau Beds.

A rich and varied fauna is known from the Gosau Beds, and by far the larger majority of the species are peculiar to them. The corals, foraminifera, polyzoa, and entomostraca have been described by Reuss; the lamellibranchiata by Zittel; the gasteropoda by Zekeli, Reuss, and Stoliczka; the cephalopoda by Franz von Hauer; and the reptiles of Neue Welt by Bunzel and Seeley. (See Bibliography, p. 122.)

Most of the organic remains occur in the fossiliferous marl-series, while a good many are found in the Estuarine group and the limestone-beds below it. Hippurites are extremely abundant, though local, and build up great banks or reefs of hard limestone: *Hipp. cornu-vaccinum* being the commonest species. Reef-building corals are extremely plentiful, especially in the Nefgraben. It is interesting to notice the almost entire absence of echinodermata, which are so characteristic a feature in the Upper Cretaceous rocks of North-western Europe, such as *Holaster*, *Micraster*, *Echinoconus*, etc.; also the great scarcity of cephalopoda and brachiopoda, while the lamellibranchiata and gasteropoda are extremely abundant. The reptile fauna described by Seeley comes entirely from the Estuarine Beds of Neue Welt. These beds also contain the remains of a highly heterogeneous flora, comprising a true palm, together with *Pecopteris Zippei*, *Microzamia*, *Cunninghamites*, and leaves of a dicotyledonous tree resembling magnolia, etc., evidently the mingling of the younger dicotyledonous type with a number of surviving older forms.

The first intimation of the existence of a freshwater fauna in these beds was given by Dr. Hörnes, who in 1856 mentioned a *Melanopsis Pichleri* among the Gosau fossils collected by Herr Pichler in the Brandenberger Ache, in the Tyrol. This gasteropod was discovered at two localities in the Brandenberger Ache. In one place it is found in great quantities with *Chemnitzia Beyrich* (Zek.), while *Nerinæa*

Buchi (Kefst.) and *Actæonella Renauxiana* (d'Orb.) also occur. At the other locality it was found only with innumerable *Chemnitziæ*, in a dark argillaceous marl, with thin layers of coal. The abovementioned *Chemnitzia Beyrichi* is, however, probably not a true *Chemnitzia*, and strongly resembles the shell described by Stoliczka as *Melania granulato-cincta*.

Cephalopoda are rare in the Gosau district, the majority of the species described being from other localities. Brachiopods also are of extremely local occurrence; the following, however, occur in the Russbachthal, on the Traunwand:—

Terebratula biplicata (Sow.).
Terebratulina gracilis (Schl.).
Waldheimia tamarindus (Sow.).
Rhynchonella compressa (Lam.).
Thecidium? Wetherelli (Dav.).

Moreover *Thecidium ornatum* (Suess) and *Crania?* sp. occur in the Hofergraben. From other localities we get:—

Terebratula biplicata (Sow.).	Abtenau and Piesting.
Terebratulina striata (Wahlb.).	Near Piesting.
Waldheimia tamarindus (Sow.).	Abtenau.
Rhynchonella compressa (Lam.).	Grünbach.

Out of the 140 species of corals, described by Reuss, only 29 occur in other besides the Gosau Beds. The genus *Cyclolites* is extremely common throughout, especially the species *C. hemisphærica* and *C. discoidea*. Amongst other very common and characteristic forms we may mention *Trochosmilia complanata* (E. & H.), the genus *Astrocœnia*, and *Montlivaltia rudis*.

Of the lamellibranchs, of course the *Rudistæ* are extremely characteristic and numerous; the following species are known from the Gosau Beds:—

Hippurites cornu-vaccinum (Bronn).
—— *sulcatus* (Defr.).
—— *Toucasianus* (d'Orb.).
—— *dilatatus* (Defr.).
—— *exaratus* (Zitt.).
—— *organisans* (Montf.).
Radiolites Mortoni (Mant.).
Sphærulites angeiodes (Pic. de Lap.).
—— *styriacus* (Zitt.).
Plagioptychus (*Caprina*) *Aguilloni* (d'Orb.).

Amongst the others, *Janira* (*Neithea*) *quadricostata* (Sow.), *Panopæa frequens* (Zitt.), and *Cardium productum* (Sow.) are extremely common. *Cucullæa chiemiensis* (Gümb.), *Crassatella macrodonta* (Sow.), and *Inoceramus Cripsi* (Mant.) are also common, and appear rather to characterize the upper portion of the fossiliferous marls.

I did not find *Cardium* (*Protocardia*) *hillanum* (Sow.), *Trigonia limbata* (d'Orb.), or *Pectunculus Marrotianus* (d'Orb.), which are also fairly characteristic forms, the latter two being common in the Hofergraben, and the *Pectunculus* also in the Wegscheidgraben. The following freshwater bivalves occur in the Estuarine series:—

Cyclas gregaria (Zitt.)	St. Wolfgang, Neue Welt, Neue Alp.
—— *ambigua* (Zitt.)	,, ,, ,,
Cyrena solitaria (Zitt.)	Neue Alp.
Unio cretaceus (Zitt.)	St. Wolfgang, Grünbach.

Amongst the gasteropoda, *Ampullina* (or *Amauropsis*, originally *Natica*) *bulbiformis* (Sow.) and *Natica lyrata* (Sow.) occur in thousands; also *Cerithium reticosum* (Sow.). Zekeli described about 47 species of *Cerithium* from these beds, but these were reduced to about a third of that number by Stoliczka, on the ground that many of the species were founded on broken fragments of the spines of other species, or were established on insufficiently constant characters. Thus the species *Cerithium reticosum* (Sow.) includes *C. pustulosum* (Sow.), which is merely a variety and passes imperceptibly into the type, *C. cribriforme* (Zek.), *C. lucidum* (Zek.), *C. dædalum* (Zek.), and several others. *Glauconia* (or *Omphalia*) *Kefersteini* (d'Orb.) is found with *Actæonella* at Traunwand and in the brackish-water beds of the Estuarine series at Neue Welt. *Nerinæa nobilis* (Münst.) and *N. Buchi* (Kefst.) both belong to the limestone-beds (*Nerinæa*-limestone), which come above the lowest Hippurite-limestone. *Nerinæa flexuosa* (Sow.) and *N. gracilis* (Zek.) seem to belong to definite zones, in which they occur in swarms, rather low down in the fossiliferous marl series. *Actæonella* is very characteristic: *A. gigantea* (Sow.) occurs in great numbers in conglomerate and coarse sandstone, frequently in a rather crushed condition, in the Rontograben. *Volvulina lævis* (d'Orb.), originally assigned to the genus *Volvaria* and then to *Actæonella*, is also of rather local occurrence, but is very common where it does occur. *Aporrhais* (*Alaria*) *costata* (Sow.), originally assigned to *Rostellaria*, is extremely common in most localities. Several species of *Voluta* were described by Zekeli, but these have all been assigned to other genera by Stoliczka, such as *Volutilithes*, *Neptunea*, *Mitra*, etc., thus:—

Voluta Bronni (Zek.)	=	*Volutilithes acuta* (Sow.).
—— *raricosta* (Zek.)	=	—— *Casparini* (d'Orb.).
—— *crenata* (Zek.)	=	*Neptunea crenata* (Zek.).
—— *cristata* (Zek.)	=	*Mitra cancellata* (Sow.).

Fusus cingulatus (Sow.) is very common, especially in the Edelbachgraben; Stoliczka, however, doubts whether this form really belongs to the genus *Fusus*.

The outer shell of both gasteropoda and lamellibranchiata is, on the whole, by no means well preserved in the fossiliferous marls, so that specific identification is frequently somewhat difficult. Perhaps the lamellibranchiata are generally the better preserved of the two, the gasteropoda being more apt to get broken or merely to be preserved as casts. *Cerithium* and *Turritella* are generally fairly well preserved, and the shells of *Melania* and *Tanalia* in the coal-bearing beds of the Neue Alp are exceedingly tough, though generally rather flattened by pressure.

By far the larger majority of the Gosau fossils are peculiar to these beds, only about 124 species out of considerably over 500 occurring in other formations outside the Eastern Alps, and the distribution of these we shall have now to consider in discussing the geological horizon of the beds.

IV. Geological Horizon of the Gosau Beds.

This question can be considered from two aspects: (*a*) stratigraphically, and (*b*) palæontologically.

(*a*). As we have already seen, the Gosau Beds almost everywhere rest with a marked unconformity upon the older Alpine Triassic and Rhætic limestones, and only at one locality do they rest on older Cretaceous beds. However, the section at Urschlauer Achen, near Salzburg, which I refer to, establishes the fact that the Gosau Beds are younger than the Gault. The Gosau fossils from this locality occur, according to Dr. Oppel,[1] in a dark marl, which is overlain by Orbitulitenkalk, and rests on Neocomienmergel with *Crioceras*; this in turn rests on Kimmeridgekalke. Sedgwick and Murchison supposed that the lowest Hippurite-limestone rested unconformably on the older Alpine limestone, and that the Gosau Beds overlay unconformably the Hippurite-limestone; but it has since been conclusively shown that the coarse basement-conglomerate comes below the Hippurite-limestone, and appearances only can be said to lend any support to the view that the conspicuous banks of Hippurite-limestone rest immediately against the older Triassic rocks, and that the rest of the Gosau series does not follow them in conformable sequence. Also the Gosau Beds are never seen to pass upward into any younger formation. Sedgwick and Murchison supposed that the unfossiliferous sandy marls, sandstones, and grits at the top of the Gosau series of the Gosauthal were of Tertiary age,[2] while on palæontological grounds they believed that the fossiliferous series represented passage-beds between the Upper Chalk and the Lower Eocene. But we shall see from palæontological considerations that the fossiliferous series cannot represent such passage-beds. It passes up imperceptibly into the unfossiliferous group, and there is a very gradual dying out of molluscan remains, so that no definite line of demarcation can be drawn between them. The majority of authors who have written on the subject decidedly agree in regarding the Gosau Beds as constituting one complete formation, which is singularly isolated stratigraphically. We shall find that more important results will follow from considering the question of the geological horizon.

(*b*). In doing so, it may be as well, first of all, to summarize the opinions of the various authors who have expressed views on palæontological grounds as to the age of the Gosau Beds.

Ami Boué studied the Gosau Beds in the neighbourhood of Grünbach, Neue Welt, in 1822. He took them at first for Jurassic, but subsequently changed his opinion in 1824, and correlated them with the Greensand or Quadersandstein.[3] Keferstein[4] included the

[1] Zittel, Denkschrift. d. kaiserl. Akad. Wissensch. Wien, vol. xxv. (1866) pt. ii. p. 162.

[2] Trans. Geol. Soc. ser. 2, vol. iii. pt. ii. (1832) p. 359.

[3] See Zittel, *op. supra cit.* p. 174.

[4] 'Geologie von Teutschland,' vol. v. 1827.

Gosau Beds together with the Vienna Sandstone in the Flysch, although Count Münster[1] had already collected a number of undoubted Cretaceous fossils from the neighbourhood of Gosau and Abtenau.

Sedgwick and Murchison, as we have already seen (*op. cit.*), placed the lowest Hippurite-limestone below the whole of the Gosau series, and regarded the fossiliferous marls as passage-beds between the Secondary and Tertiary systems, and the upper unfossiliferous group as Tertiary, on the same horizon as the Molasse. Goldfuss, who described a number of fossils from the Gosau Valley, left the question of the age of the beds open. After the year 1836 geologists were, on the whole, fairly well agreed as to the Upper Cretaceous age of the Gosau Beds, though we still find Klipstein in 1843 upholding their Tertiary age.[2] Murchison, following up the investigations undertaken in conjunction with Sedgwick, published in 1849 a paper on the Geological Structure of the Alps, Apennines, and Carpathians.[3] In this he changes his former opinion, and believes that the fossiliferous beds of Gosau are the equivalents of the Gault, Upper Greensand, and Lower Chalk. He still, however, thinks that the upper part of the Gosau series without fossils represents a portion of the Nummulitic and Flysch series of other districts, while the Hippurite-limestone is the equivalent of the Neocomian.

Franz von Hauer in 1850[4] correlated the Gosau Beds with the Obere Kreide and the Pläner- and Quadersandstein formation of Northern Bohemia and Saxony, and later (1878), in his 'Geologie der österr.-ungarischen Monarchie' (p. 516), he classes them as Turonian, and places the Nierenthaler Schichten, which occur at Nierenthal in Bavaria and near Gmünden in Upper Austria, in the Senonian with *Belemnitella mucronata* and *Ananchytes ovata*.

Up to about this date the fauna of the Gosau Beds was very imperfectly known, and it was from the want of a more accurate knowledge of this and of Cretaceous faunas in general that the idea of their Tertiary or Cretaceo-Eocene age had been entertained by some of the earlier observers. Probably, also, the generally soft and rather crumbling nature of the deposits, and the loosely-embedded mode of occurrence of the fossils, seemed to lend support to this view.

In 1852 Zekeli published a monograph on the gasteropoda,[5] in which he concluded that out of 190 species only 23 occurred outside the province of the North-eastern Alps, that the fauna showed a highly specialized facies, and that it would be difficult to correlate the beds with any known Cretaceous formation. Out of the 23

[1] Count Münster's collection is now in the Woodwardian Museum, Cambridge.

[2] 'Beiträge zur geologischen Kenntniss der östlichen Alpen,' p. 24.

[3] Quart. Journ. Geol. Soc. vol. v. p. 157.

[4] Jahrb. d. k. k. geol. Reichsanst. vol. i. p. 44.

[5] 'Die Gasteropoden der Gosaugebilde,' Abhandl. d. k. k. geol. Reichsanst. vol. i. pt. ii.

already known species Zekeli found that 11 occurred in the Turonian, 7 in the Senonian, 3 in the Turonian and Senonian together, and 2 in the Gault; so he concluded that the Gosau Beds represented both the Senonian and the Turonian.

In 1854 Reuss[1] described the foraminifera, polyzoa, entomostraca, and corals of the Gosau Beds. He found that, of the species of Gosau fossils known elsewhere, by far the greater number appear in the Turonian system of d'Orbigny, and that therefore the Gosau Beds represent the Turonian. The Turonian character, according to Reuss, comes out especially in the calcareous and marly beds, characterized by their abundance of *Rudistæ*, corals, *Nerinæa*, and *Actæonella*. He thinks, however, that some of the lower beds of the Senonian system may be represented at Gosau and elsewhere, and formulates his conclusion thus (p. 46):—"The Gosau Beds constitute a complete and unique formation, in which marls, limestones, calcareous sandstones, and conglomerates alternate irregularly with one another, and this formation should preferably be correlated with the Turonian system, and perhaps the uppermost beds with the lower part of the Senonian system." Reuss's results would certainly require further confirmation, since at the time when he wrote there were no descriptions of the Gosau cephalopoda, brachiopoda, or lamellibranchiata. Gümbel follows Reuss, and calls the Gosau Beds Turonian.[2]

In 1865 and 1866 appeared Zittel's monograph on the lamellibranchs.[3] Out of 140 species here described, 88 are peculiar, while the remaining 52 occur in other places. These 52 are distributed as follows:—

In the Neocomian and Gault we get:—

Modiola æqualis (Sow.).—Neocomian and Quadersandstein (Bohemia);
Inoceramus Cripsi (Mant.).—Gault to Upper Chalk, very common in North-western Europe,

to which I may add *Cardita tenuicosta* (Sow.)—Gault, found by me, I believe for the first time, in the Hofergraben.

In the Cenomanian (Upper Greensand, Carentonian, Lower Quadersandstein) we find 20 species, among which I may mention:—

Tapes fragilis (d'Orb.).	*Gervillia solenoides* (Defr.).
Circe discus (Math.).	*Inoceramus Cripsi* (Mant.).
Cardium productum (Sow.).	—— *latus* (Mant.).
Protocardia hillana (Sow.).	*Janira quadricostata* (Sow.)
Trigonia scabra (Lam.).	*Ostrea vesicularis* (Lam.).
Modiola æqualis (Sow.).	

and the majority of these are best represented in the Turonian. In the Pläner of North Germany, Saxony, Bohemia, and Silesia we find 17 species, and 17 species also in the Quadersandstein. In the

[1] 'Beiträge zur Charakteristik der Kreideschichten in den Ostalpen,' Denkschrift. d. kaiserl. Akad. Wissensch. Wien, vol. vii. p. 1.
[2] 'Geognostische Beschreibung d. Bayerischen Alpengebirges,' pt. i. p. 517.
[3] Denkschrift. d. kaiserl. Akad. Wissensch. Wien, vol. xxiv. pt. ii. p. 105, & vol. xxv. pt. ii. p. 77.

Upper Chalk with *Belemnitella mucronata* of Northern Germany and Northern France we find 18 species, amongst which are :—

Cardium productum (Sow.).	*Pecten lævis* (Nilss.).
Trigonia limbata (d'Orb.).	—— *virgatus* (Nilss.).
Pinna cretacea (Schl.).	—— *cretosus.*
Gervillia solenoides (Defr.).	—— *membranaceus* (Nilss.).
Inoceramus Cripsi (Mant.).	*Janira quadricostata* (Sow.).
—— *Lamarcki* (Park.).	—— *substriatocostata* (Sow.).
—— *latus* (Mant.).	*Ostrea vesicularis* (Lam.).
Lima decussata.	

In the sub-stage Campanien we find 13 species.
" " Angoumien " 7 "
" " Mornasien " 15 "
" " Provencien " 15 "

Out of the 15 Provencien species 7 are only found elsewhere in the Gosau Beds, and these 7 are all *Rudistæ*, namely :—

Hippurites cornu-vaccinum (Bronn).	*Hippurites dilatatus* (Defr.).
—— *sulcatus* (Defr.).	—— *organisans* (Montf.).
—— *Toucasianus* (d'Orb.).	*Sphærulites angeiodes* (Pic. de Lap.).
	Caprina Aguilloni (d'Orb.).

These are, of course, extremely characteristic and common, and belong to the most characteristic forms of the zone of *Hippurites cornu-vaccinum*, which forms one of the best-marked horizons in the Cretaceous system. Zittel concludes from his study of the distribution of the Gosau lamellibranchs "that the Gosau Beds belong to the zone of *Hippurites cornu-vaccinum* or Étage Provencien (Coquand), and do not represent the Turonian and Senonian combined." He finds that this conclusion is also supported by the facts of the distribution of the gasteropoda and corals. Of the brachiopoda none are restricted to any definite horizon. Thus, out of the 8 species known, we find :—

2 in the Neocomian and Gault.
5 " Cenomanian.
2 " Plänerkalk.
1 " Lower Chalk.
2 " Santonian.
3 " Upper Chalk with *Belemnitella mucronata.*

Stoliczka reduced the gasteropoda described by Zekeli from nearly 200 species to about 124. By far the larger majority of these are confined to the North-eastern Alps, only a small number occurring in the South of France. Out of the 26 species which occur outside the Eastern Alps we get, according to Zittel, 21 in the Provencien, of which 14 occur in the blue marls of Corbières. Among them we may mention :—

Actæonella gigantea (Sow.).	*Fusus cingulatus* (Sow.).
Volvulina lævis (d'Orb.).	*Alaria costata* (Sow.).
Nerinæa Buchi (Kefst.).	—— *granulata* (Sow.).
Omphalia Kefersteini (Münst.).	*Astralium radiatum* (Zek.).
—— *Renauxiana* (d'Orb.).	*Phasianella gosauica* (Zek.).
Ampullina (*Natica*) *bulbiformis* (Sow.).	*Cerithium furcatum* (Zek.).
Natica lyrata (Sow.).	—— *reticosum* (Sow.).
—— *angulata* (Sow.).	—— *provinciale* (d'Orb.).

Out of the 140 or more species of corals, most of which are peculiar to the Gosau Beds, 20 are found in the Provencien. Thus, taking the corals, bivalves, and gasteropoda together, we find 56 species in the Provencien, and this is a far larger number of species than is found in any other sub-stage, according to Zittel. He finally concludes that the Gosau Beds are Turonian, that they belong only to the zone of *Hippurites cornu-vaccinum* (Provencien), and that they represent a unique and remarkable development of that horizon, indicated by the richness of their fauna and its large number of peculiar forms.

There seems no doubt whatever that the Provencien zone of *Hippurites cornu-vaccinum* occurs in the lower part of the Gosau series; but it does not follow that the Gosau Beds merely represent a remarkable development of this one horizon only. It is, indeed, by no means easy to correlate these beds exactly, seeing that we have no stratigraphical data and considering their peculiar fauna, with any well-known zone or zones of Western Europe; nor does there seem to be an entire agreement amongst geological writers as to exactly what should constitute the Turonian and what the Senonian system. Possibly some confusion might be avoided if these terms were altogether ignored in a discussion of this sort, and reference only made to zones, which are probably, under the present methods of stratigraphical enquiry, a surer indication of a geological horizon than names for systems and stages which can only have a more or less local significance.

Zittel occupies the last part of his monograph with a sketch of the principal features of the strata included in the sub-stage Provencien of the South of France, and with a few remarks on the wide distribution in Southern Europe and Asia of the zone of *Hippurites cornu-vaccinum.* The term 'Provencien,' however, does not seem to have come into general use, many geologists including the zone of *Hipp. cornu-vaccinum* in the sub-stage Angoumien; but this is not of any particular importance. A mere question of terms cannot alter a geological horizon.

As an example of the confusion which may arise from the use of the terms 'Turonian' and 'Senonian' in connexion with such stratigraphically isolated deposits as the Gosau Beds, I will quote two passages, both from the pens of eminent geologists. In 1881 appeared Prof. H. G. Seeley's description of the Reptile Fauna of the Estuarine Series of Neue Welt,[1] appended to which was a note by Prof. Suess. In this, however, Suess omits to mention the occurrence of Hippurite-limestone below this series in the Gosau Beds, and finally remarks, "I cannot, therefore, say positively that the age of the Reptiles . . . . is exactly that of your Cambridge Phosphate-beds; but it is certain that they are *older* than the true Turonian deposits, and especially older than the zone of *Hippurites cornu-vaccinum.*" Turning now to Toucas's paper,[2] entitled 'Synchronisme des Étages Turonien, Sénonien et Danien dans le Nord

[1] Quart. Journ. Geol. Soc. vol. xxxvii. p. 620.
[2] Bull. Soc. Géol. France, ser. 3, vol. x. pp. 200-202.

et dans le Midi de l'Europe,' published in 1882, we read (p. 200): "All are agreed in recognizing the essentially *Sénonien* character of the Gosau fauna." But he goes on to say that Zittel, Reuss, and others were "misled by the papers of d'Orbigny, and especially by those of Coquand on the Turonian and Senonian of the South of France, and particularly as to the position which they assign to the Hippurite-deposits," so that "in default of other terms of comparison" they correlated the Gosau Beds with the Turonian. Since, however, Toucas's conclusions in his valuable paper referred to above seem to be extremely important, it will be well to look into them more closely. Apparently Zittel modified his former views as to the age of the Gosau Beds after comparing them, in company with Toucas, with the beds of Beausset in the South of France; and now Zittel classes as Senonian the Hippurite-beds of La Cadière and Beausset, as well as the marls and limestones with *Inoceramus digitatus* which support them.

The beds of La Cadière, Beausset, Sougraigne, and other places in the South of France, belong to the zones of *Belemnitella* and the 2nd zone of *Hippurites*, and have been correlated with the Gosau Beds.

Toucas finds 19 species of fossils common to the Gosau Beds and the Senonian zones of *Ceratites* and *Micraster brevis* of Provence and Corbières, 18 to the Gosau Beds and the zone of *Inoceramus digitatus*, and 63 common to the same beds and the zones of *Belemnitella* and the 2nd zone of *Hippurites*. He concludes that the distribution of the Gosau fossils proves that the Gosau Beds represent the whole of the Senonian from the Craie de Villedieu to the zone of *Belemnitella* inclusive. It is true, as Toucas remarks, that we do not find in the Gosau Beds a single characteristic Turonian species such as *Ammonites Requieni*, *A. peramplus*, *A. papalis*, *A. Deveri*, *A. nodosoides*, nor any of the *Rudistæ* such as *Hipp. Requieni*, *Radiolites cornu-pastoris*, *Sphærulites ponsianus*, so abundant in the first zone of *Hippurites*, which he places at the top of the Turonian. Furthermore, the presence in the Gosau Beds of *Amm. texanus*, *A. subtricarinatus*, *A. Margæ*, *Hamites cylindraceus*, etc., certainly indicates a post-Turonian age, occurring as they do in the zone of *Inoceramus digitatus*.

But still there seems to be some slight confusion with regard to the *Rudistæ*. In the Gosau Beds, as we have already seen, Hippurite-limestones occur at two distinct horizons; thus we get the Hippurite-limestone immediately above the basement-conglomerate, characterized essentially by *Hipp. cornu-vaccinum*. This is overlain by the *Actæonella* and *Nerinæa*-limestones and the Estuarine series, and then we get Hippurite-limestone occurring again in the fossiliferous marls, this time characterized essentially by *Hipp. organisans*, while *Hipp. cornu-vaccinum*, *Sphærulites angeiodes*, and *Plagioptychus* (*Caprina*) *Aguilloni* also occur. Now, in the South of France also, Toucas distinguishes two distinct zones of *Hippurites*: the first, which he places at the top of the Turonian system, is the zone characterized essentially by *Hipp. cornu-vaccinum*; while in

the second, which he places towards the top of the Senonian, we find *Hipp. organisans*, *Hipp. cornu-vaccinum*, *Sphærulites angeiodes*, and *Plagioptychus Aguilloni* (*op. cit.* p. 202).

Toucas seems to have lumped together all the species of *Rudistæ* found in the Gosau Beds, and to have referred them to his 2nd zone of *Hippurites*. But surely it would be more natural to keep the two Gosau zones separate, since stratigraphical evidence is so strongly in favour of their being distinct, and to correlate them with the 1st and 2nd zones of *Hippurites* respectively of the South of France. Thus we should have the zone of *Hipp. cornu-vaccinum* remaining intact near the base of the Gosau series, and being the equivalent of the uppermost portion of the Turonian system of Toucas. We should hardly expect to find at Gosau such ammonites as *A. Requieni*, *A. peramplus*, *A. papalis*, *A. Deveri*, *A. nodosoides*, since the majority of these occur in the South of France below the first zone of *Hippurites*, or the zone of *Hipp. cornu-vaccinum*, which zone is the first stratum of the Gosau Beds wherein any fossils occur.

Dr. Emmanuel Kayser alludes briefly to the Gosau Beds in his 'Lehrbuch der geologischen Formationskunde' (Stuttgart, 1891), and remarks (p. 280) that the lower beds belong to the Turonian, and the higher to the Senonian. Toucas's objection to any part of the Gosau series being considered as of Turonian age is that, when one does find Turonian species in them, such as those of Uchaux in the South of France, they are only those which pass up into higher beds. But when we consider how strong the evidence is in favour of the occurrence of the true zone of *Hipp. cornu-vaccinum* at Gosau and other places in the Eastern Alps, and bearing in mind the considerations brought forward above with regard to the two zones of *Hippurites*, we cannot but conclude that the basal portion of the Gosau Beds should be correlated with the zone of *Hipp. cornu-vaccinum*, included in the first zone of *Hippurites* at the top of the Turonian system.

Passing from the zone of *Hipp. cornu-vaccinum* to the Senonian zones of Provence and Corbières, we find (Toucas, *op. cit.* pp. 210–217) that the larger proportion of the fossils from the Gosau Beds occur also in the zone of *Belemnitella* and the 2nd zone of *Hippurites* in the upper part of the Senonian. Hence we shall not be far from the mark in concluding that the Gosau Beds represent the uppermost Turonian, and the whole of the Senonian of the South of France—that is to say, from the zone of *Hippurites cornu-vaccinum* to the zone of *Belemnitella* inclusive. In Touraine and in the Paris Basin the same horizon is defined from the zone of *Amm. Requieni* in Touraine [= zone of *Holaster planus* and *Am. peramplus* in the Paris Basin] to the zone of *Belemnitella mucronata*, and hence in the English Upper Cretaceous rocks we shall find the representatives of the Gosau Beds in the zones of *Holaster planus*, *Micraster*, *Marsupites*, and *Belemnitella mucronata*—that is to say, from the horizon of the Chalk Rock to the top of the Chalk-with-flints inclusive.

If we endeavoured to correlate the Gosau Beds with English Cretaceous zones by a direct comparison of their fauna with English Upper Cretaceous faunas, we should find a rather difficult task awaiting us. There are very few fossils common both to the Gosau Beds and the English Upper Cretaceous rocks; and those Gosau species which are found in England are, as a rule, not confined to any particular horizon, but frequently have a fairly extensive distribution in the Cretaceous system.

From Murchison's paper,[1] as we have already pointed out, we may gather that he correlated the Lower or more fossiliferous portion of the Gosau Beds with the Gault, Upper Greensand, and Lower Chalk, while he assigned the Hippurite-limestone to the Neocomian. But he still clung to the idea that some of the Upper part of the series might represent passage-beds from the Chalk to the Tertiary system. Hence, the whole of the Gosau Beds would represent, according to his views, all the English formations from the Neocomian to the top of the Chalk, and would furnish the missing overlying passage-beds as well. But, as these views have been already discussed, we need not enter into them further.

Judging from Suess's Note, appended to Prof. Seeley's paper, a few remarks from which I have already quoted, we may conclude that Prof. Seeley had some idea that the Estuarine beds of the Gosau series, from which the reptilian remains so admirably described by him were collected, might be on the same horizon as the Cambridge Greensand. But, as we have already seen, from a comparison of the Gosau fauna with the Senonian and Turonian faunas of the South of France, it is highly probable that the Gosau Beds commence with the zone of *Holaster planus* or the Chalk Rock, whereas the Cambridge Greensand occurs at a very much lower horizon, namely at the base of the Chalk Marl. At the commencement of his paper, too, Seeley speaks of the Gosau Beds as "nearly corresponding in age to the Upper Greensand of this country," and in consequence of this we find that some of the reptiles he has described are referred to in Nicholson and Lydekker's 'Manual of Palæontology' as occurring in the "Upper Greensand of Austria" (see vol. ii. pp. 1160, 1163).

Seeley revised Bunzel's work on the 'Reptiles of Neue Welt,' published in 1871, and described altogether 14 genera and 18 species, and all the species are peculiar. There are certainly 7 Deinosaurs, 1 each of Crocodiles, Lizards, and Pterodactyls, 2 genera and 5 species of Chelonians. Out of the 14 genera only the following 5 are known in England:—*Crocodilus*, *Megalosaurus*, *Ornithocheirus*, *Hoplosaurus*, and *Emys*. The *Crocodilus* is characteristic of Tertiary and Recent times; *Megalosaurus* ranges from the Lower Jurassic to the Upper Cretaceous of Maastricht; *Ornithocheirus* characterizes Cretaceous rocks, *Hoplosaurus* Wealden; and *Emys* ranges from the Lower Eocene (or Gosau Beds, according to Seeley) to recent times. The only two genera of these which occur in the Cambridge Greensand are *Ornithocheirus* and *Crocodilus*, and of these the latter genus does not seem to be recognized as of

[1] Quart. Journ. Geol. Soc. vol. v. (1849) p. 157.

Cretaceous age by Lydekker. Thus we cannot hope to get much result from studying the reptiles of Neue Welt as to the geological horizon of the beds in which they occur.

Neither do we get any further help from the cephalopoda, as none of them are characteristic of any particular English horizon, the form best known in England, viz. *Scaphites æqualis* (Sow.), ranging from the Gault to the Chalk Rock.

Probably none of the Gosau species of gasteropoda occur in any English Cretaceous beds whatsoever. It is doubtful whether *Aporrhais calcarata* (Sow.) of the Gault and Upper Greensand of Blackdown occurs at Gosau, the form from Gosau, originally named *Rostellaria calcarata* (Sow.), having been assigned by Stoliczka to *Alaria* (probably *Aporrhais*) *granulata* (Sow.). In fact only a very few gasteropoda at all are common to the Gosau Beds and the North of Europe, e. g. *Turritella Eichwaldiana* (Goldf.), occurring in the Upper Chalk of Haldem; *Nerinæa Buchi*, *N. flexuosa*, and *Volvulina lævis*, in Bohemia; *Natica lyrata*, in North Germany; and *Fusus Nereidis* (Münst.), in the Chalk of Haldem.

Coming now to the lamellibranchiata, we find the following Gosau species in English Cretaceous beds, with the subjoined distribution:—

NEOCOMIAN	*Modiola æqualis* (Sow.)......	Atherfield.
GAULT	*Cardita tenuicostata* (Sow.).	
	Gervillia solenoides (Defr.).	
	Ostrea vesicularis (Lam.).	
	Janira (*Neithea*) *quadricostata* (Sow.).	
	Inoceramus Cripsi (Mant.).	
UPPER GREENSAND	*Protocardia hillana* (Sow.) .	Blackdown.
	Gervillia solenoides (Defr.) .	Warminster.
	Janira (*Neithea*) *quadricostata* (Sow.).	Blackdown and Isle of Wight.
	Cypricardia testacea (Zitt.).	Comes very near *Cyprina cuneata* (Sow.) from the Blackdown beds.
LOWER CHALK ...	*Cardita tenuicostata* (Sow.).	Gault forms occurring as derived fossils in the Cambridge Greensand (see Geol. Surv. Mem. on Geology of Neighbourhood of Cambridge, p. 152).
	Gervillia solenoides (Defr.) .	
	Ostrea vesicularis (Lam.) ...	
	Janira (*Neithea*) *quadricostata* (Sow.).................	
	Ostrea vesicularis (Lam.).	
	Spondylus striatus (Sow.).	
	Radiolites Mortoni	Also in Cambridge Greensand.
	Inoceramus latus (Mant.).	
MIDDLE CHALK ...	*Ostrea vesicularis* (Lam.).	
	Inoceramus latus (Mant.).	
UPPER CHALK ...	*Ostrea vesicularis* (Lam.).	
	Pecten virgatus (Nilss.).	
	—— *cretosus* (Defr.).	
	—— *lævis* (Nilss.).	
	Janira (*Neithea*) *substriatocostata* (Sow.).	
	Inoceramus Cripsi (Mant.).	
	—— *Lamarcki* (Park.).	
	—— *latus* (Mant.).	

	Gosau Beds.	English Chalk Zones.		
Upper	Upper Series of Marls, Sandstones, etc., with obscure plant-remains, and worm-tracks	(Absent)		? Danian.
Lower	Fossiliferous Marls and 2nd zone of *Hippurites*, Estuarine Series, Limestones with *Actæonella* and *Nerinæa*	Zone of *Belemnitella mucronata* Zone of *Marsupites* Zone of *Micraster*, var. sp.	Upper Chalk.	Senonian.
	Limestones with *Hipp. cornu-vaccinum* and Conglomerate.........	Zone of *Holaster planus* or Chalk Rock	Middle Chalk.	Turonian.

V. Physical History of the Gosau Beds.

Probably the whole series of the Gosau Beds was deposited in fairly shallow water. At the base we find conglomerates, marls, and limestones, with *Hippurites*, *Actæonella*, *Cerithium*, *Nerinæa*, etc., beds which are evidently of marine origin, and the limestones are almost entirely made up of forms which most probably dwelt in shallow water. The *Hippurites* lived in colonies, like oysters, and built up great banks or reefs, resembling barrier-reefs, along the rocky coasts of older Triassic and Rhætic limestones, whose fragments constitute the basement-conglomerate. Above the limestones we find a series of beds containing a fauna consisting of a mixture of marine and freshwater forms and land-plants. This probably indicates the neighbourhood of the mouth of a river. Stoliczka, referring to the nature of these beds, remarks :—"One can see from these occurrences that during part of the Cretaceous period the valleys of our Alps stood high enough above the sea-level for fresh water to flow down them. These streams or torrents, with their unusually richly ornamented molluscs and the strange assemblage of plants on their banks whose remains have formed the small layers of coal, give the palæontologist a characteristic illustration of a mountain-region in the Chalk period." [1] But I fail to see how the facts illustrate any such thing. The organic remains in the beds certainly prove that they were deposited near the mouth of a river, and possibly part of them may be entirely of freshwater origin, but it seems highly improbable that they could have been deposited so far above the sea-level as to give us molluscs and land-plants of a mountain facies. The whole assemblage denotes estuarine conditions ; and the floor of this estuary evidently underwent gradual depression, as we find the brackish-water beds gradually passing into the thick series of fossiliferous marls with their rich and entirely marine fauna. Here, again, we find Hippurite-banks and

[1] Sitzungsber. d. kaiserl. Akad. Wissensch. Wien, vol. xxxviii. (1859) p. 482.

coral-reefs, and the whole is of a littoral facies and denotes a tropical climate.

When we reach the top of this series, however, conditions seem gradually to have altered, and we find quite shallow-water deposits constituting the micaceous sandstones and flags, with occasional bands of coarse grit. The abundant ripple-marks, worm-tracks, and obscure remains of plants and fragments of wood are sufficient proof of their shallow-water origin and the proximity of land. The mica so abundant in these beds was probably derived from the denudation of some of the older schistose and gneissic rocks of the central portion of the chain. Depression, however, gradually followed again, and we get beds of rather deeper-water origin, viz. the sandy, red, grey, and mottled marls, without any organic remains, and these again are succeeded by shallower-water beds, forming the grits and conglomerates at the top of the whole series. There is nothing to prove whether these unfossiliferous beds were of fresh-water or marine origin. It is evident that elevation was going on towards the close of the period in which the fossiliferous marls were deposited, and it is rather difficult to account for so complete, though so gradual, a change in the lithological and palæontological character of the rock, unless we suppose that at about that time the Gosau district was cut off by this elevation from free communication with the open sea, and constituted for the rest of the Cretaceous period a lake-basin.

Since the Gosau Beds of the Gosau Valley are tilted up so that their average dip is in a southerly direction—and the dip is frequently steep in the northern part of the valley, while most of the beds towards the south, especially on the Ressenberg, are almost horizontal—it would follow that the greatest amount of elevation took place in the northern portion of the area, especially since we find there the basal conglomerate at almost as high a level as the marl series of the Hornspitze. Land evidently lay to the south in the direction of the central axis of elevation of the Eastern Alps, and open sea to the north and north-west. Now it is in the north and north-west of the area that the beds are much tilted and disturbed, and in the south that we find the micaceous sandstones and sandy marls. Hence, if this elevation of the northern part of the area, which, as we have seen, began towards the close of what may be called 'the fossiliferous period,' continued to any great extent, the southern portion would have been cut off from communication with the sea, and so would have constituted a lake-basin, with a river running into it from the south.

The occurrence in the upper unfossiliferous beds of ripple-marks and worm-tracks would rather seem to negative the idea of lofty mountainous features existing in the immediate neighbourhood, since lakes in mountainous districts usually have steep, shelving sides, which would not allow of the tranquil deposition of sediment in very shallow water on an almost horizontal floor.

Several authors have supposed that the Gosau Beds were deposited in bays or fjords represented by parts of the present

valleys of the Alps.[1] But the mode of occurrence of these beds does not necessarily prove that the present valleys of the Eastern Alps were already marked out in Upper Cretaceous times. What we can say for certain is that they were deposited in trough-shaped depressions in the older Secondary rocks, and we should naturally expect, under these circumstances, that the present lines of drainage would cut through them where opportunity occurs, since they would be of a much more yielding and easily-disintegrated nature than the older rocks on which they rest.

Sedgwick and Murchison, struck by the isolated position of the Gosau Beds, supposed that several of the now-isolated patches were originally connected, and were deposited in a deep bay within the Alpine chain.[2] Probably many such patches, like those of Zlam, Gosau, Abtenau, and St. Wolfgang, were originally continuous, and were deposited in bays on the southern boundary of the great Upper Cretaceous Sea of Central and Southern Europe. Otherwise it is difficult to account for the succession of strata being almost the same in each case, if we suppose that the now-isolated patches existed as such at the time of deposition.

From the stratigraphical situation of the Gosau Beds, and the occurrence of the calcareous conglomerate at their base, it is evident that the older Secondary rocks of the Eastern Alps on which they rest had undergone elevation and denudation, with a considerable amount of earth-movement, accompanied by contortion and plication, previous to the period of depression during which these beds were deposited. During their deposition the Eastern Alps probably existed as fairly high land along the central portion of the chain, with a very irregular coast-line along its northern flanks. At the close of Cretaceous times there was probably considerable elevation, followed by depression in the Eocene period at the time of the deposition of the Nummulitic rocks and the Flysch. Then followed the period of the great Alpine uplift, a movement intense in the western portion and gradually dying out towards the east in the direction of the Vienna Basin, and it is to this period that the present structure of the mountains is chiefly due, as also the present isolated and elevated position of the several small areas covered by the Gosau Beds.

VI. Summary.

It now only remains to summarize briefly the description which I have given of the stratigraphy, palæontology, physical history, etc., of the Gosau Beds of the Gosau district.

After an account of the previous literature of the subject had been given, and the physical aspects of the Gosau Valley had been described, I pointed out that the Gosau Beds are found in various isolated trough-shaped depressions chiefly on the northern flanks of the Eastern Alps, such as the Gosau Valley, the Zlamthal (near Aussee),

[1] Zittel, Denkschrift. d. kaiserl. Akad. Wissensch. Wien, vol. xxv. (1866) pt. ii. p. 160.

[2] Trans. Geol. Soc. ser. 2, vol. iii. pt. ii. (1832) p. 367.

the Gamsthal in Styria, the basin of St. Wolfgang, and Neue Welt, near Wiener Neustadt. With one exception they are always found resting unconformably on the older Secondary rocks of the Alps, and with one exception again are never associated with either older or younger Cretaceous beds.

In the Gosau district they dip on the average in a southerly direction, and the degree of inclination varies from almost horizontal in the more southerly part of the area to an angle of about 60° towards the north and north-west. The Gosau Beds of this district correspond on the whole in their fauna and stratigraphical divisions with those of most of the other areas, and they consist of conglomerates, limestones with *Hippurites* and corals, estuarine beds with a mixed fauna, dark-grey marls crowded with molluscan remains, and micaceous sandstones, flags, and shales, sandy marls and grits, etc., without any fossils.

The fossils from the Lower beds constitute a rich and varied fauna, in which corals, gasteropoda, and lamellibranchiata are especially well represented, while cephalopoda and brachiopoda are comparatively rare, and echinodermata almost entirely absent. The greater majority of the fossils are peculiar to these beds. Those species which are found in other areas seem to prove that the Gosau Beds are of Upper Cretaceous age, and that they represent the whole of the Senonian, and the uppermost part of the Turonian system of the South of France—that is to say, from the zone of *Hippurites cornu-vaccinum* to the zone of *Belemnitella* inclusive, or in England from the zone of *Holaster planus* or the Chalk Rock to the zone of *Belemnitella mucronata* inclusive, while the Upper unfossiliferous portion of the series may possibly represent the Danian system.

The Gosau Beds are, on the whole, of shallow-water origin, with beds indicating estuarine conditions near their base, and were deposited in narrow bays in the Upper Cretaceous Sea of Southern and Central Europe on the northern flanks of the Eastern Alps. Probably, towards the close of Upper Cretaceous times, the southern area of the Gosau district was cut off from the sea so as to constitute a lake-basin, in which the Upper unfossiliferous series was deposited.

The Gosau Beds owe their present isolated and elevated position to the last great period of mountain-building in Central Europe, which took place at the close of the deposition of the Nummulitic series and the Flysch.

Discussion.

The President said that the Geological Society must ever take a deep interest in the district referred to in this paper, in consequence of the classic memoir by Murchison and Sedgwick published many years ago. Since then the district had been investigated by several distinguished geologists, and we were indebted to the Author for his excellent summary of the present state of our knowledge as to the

stratigraphy, palæontology, and physical history of these interesting deposits. No doubt there had been much pre-Cretaceous oscillation in that area before the deposition of the Gosau Beds. Whether the study of them will ever throw light on the question of Alpine upheaval appears doubtful. He would like to ask the Author whether there was any evidence of the existence of a central crystalline axis during the deposition of the Gosau Beds. As to correlation with other strata in North-western Europe, it was curious to note the occurrence of so many reef-building corals and gasteropoda in beds parallel with the *Micraster*-chalk in England.

Mr. W. Whitaker, Sir John Evans, and Prof. J. F. Blake also spoke.

The Author, in replying, said that a considerable quantity of white mica occurred in the flaggy beds of the Upper Gosau series. This he regarded as indicating the existence at that time of schistose rocks belonging to the axial portion of the chain to the south. As regards the correlation of the Gosau Beds with British Upper Cretaceous zones, he considered that such correlations were always useful, if not necessary; and although the Gosau Beds could not be directly correlated with English rocks, they could be closely compared with the Turonian and Senonian zones of the South of France, which in their turn could be correlated with the Upper Cretaceous zones of the Paris Basin and England. The Gosau Beds represented, on the whole, a distinctly littoral type of formation, and certainly could be made use of in searching for the shore-line of the Upper Cretaceous Sea in Central Europe.

11. Artesian Boring *at* New Lodge, *near* Windsor Forest (Berks). By Prof. Edward Hull,[1] M.A., LL.D., F.R.S., F.G.S. (Read December 20th, 1893.)

Having availed myself of the opportunity offered by a few weeks' residence in the neighbourhood of Windsor Forest, during the summer of 1893, to visit a remarkable boring for water carried out at New Lodge in Berkshire, of which notices appeared in several newspapers some little time ago, I propose to lay before the Society the information obtained on the occasion referred to, Monday, the 28th August last.[1]

The boring was carried down by means of the diamond drill at the rear of New Lodge, the residence of Mr. Van de Weyer, at a level of about 220 feet above Ordnance datum, and commences in the London Clay not far from the base of the Bagshot Sands, which set in a short distance southward in the direction of Windsor Forest.[2] Without going into minute details of the boring, the following summary will suffice to show the nature of the strata passed through from the surface to the total depth of 1241 feet[3]:—

		Thickness in Feet.
Tertiary...	London Clay...... .... / Lower London Tertiaries ...	214
Cretaceous Strata.	Chalk (Upper and Lower)	725
	Upper Greensand..................	31
	Gault Clay	264
	Lower Greensand..................	7
	Total...............	1241

When the boring was commenced it was expected that it would only be necessary to enter the Chalk in order to find the requisite water-supply, and a diameter at the surface of $7\frac{1}{2}$ inches was considered sufficient to allow for tubular lining to this depth. Much disappointment was, therefore, felt when it was found on reaching this formation, at a depth of 215 feet, that the rock was hard and contained very little water; and it was thereupon determined to continue the boring down into the Lower Greensand—as the next most likely source of supply. With a diameter at the commencement of only $7\frac{1}{2}$ inches some anxiety was necessarily felt as to whether this formation could be reached by means of a tubular bore with the necessary lining; and, as the result proved, the apprehension was well founded. But fortune was on the side of the experiment. The borer entered the Lower Greensand with a diameter of $1\frac{1}{2}$ inch, and had not penetrated into this formation for more than 7 feet

[1] I have to acknowledge the assistance and information readily afforded by Mr. Menzies, of Englefield Green, and by Mr. Rose, the bailiff of the estate.

[2] That the locality was originally part of this extensive forest is shown by the presence of several noble oak-trees of great age.

[3] The work was carried out by the firm of Le Grand and Sutcliff, London.

when the water gradually rose in the borehole, reaching the surface and even rising 7 feet above it in a pipe. Of course, with so small an orifice ($1\frac{1}{2}$ inch) in the water-bearing beds a large supply was not to be expected; but, notwithstanding, the supply is sufficient to give a continuous flow of 2 gallons per minute, equal to 2,880 gallons per day, and quite ample for the requirements of a very large household. The water is soft, clear, and slightly chalybeate.

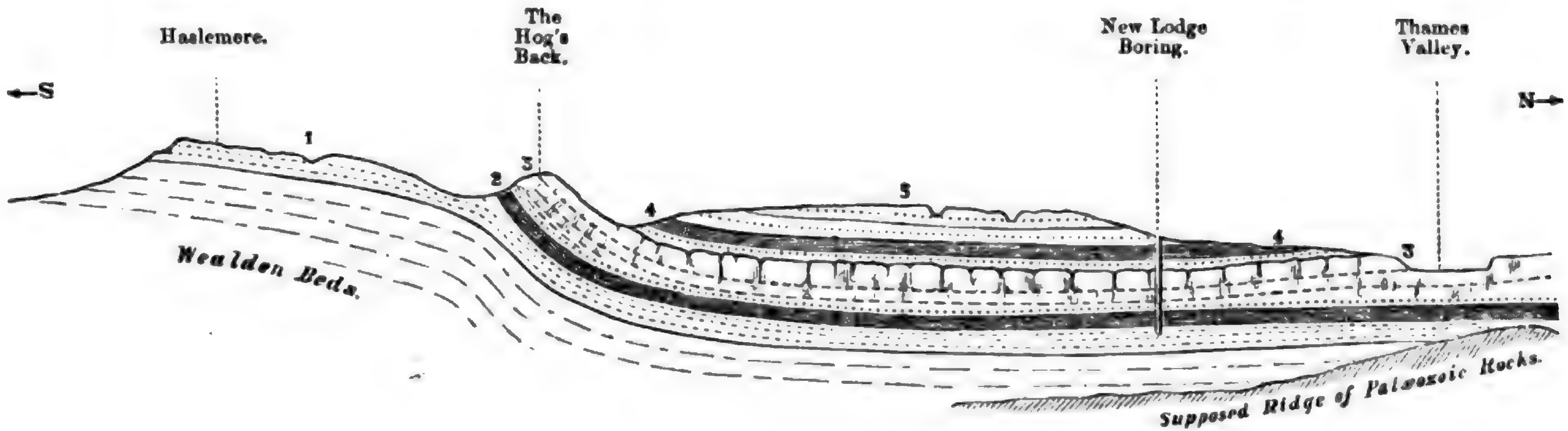
From the above account we may gather several interesting conclusions. Firstly, it will be evident that the hydrostatic pressure is very great, being sufficient to cause the water to rise 7 feet above the ground in a pipe; and we may therefore suppose that with a wider borehole a much larger supply could be obtained. We may also infer that the surface gathering-ground of the Lower Greensand is considerably more elevated than the site of the boring. The Lower Greensand crops out at about an equal distance of 20 miles north and 20 miles south of the boring: the one outcrop being in Buckinghamshire, and the other in Surrey, near Guildford. But the surface-area in the former case is interrupted and never extensive, while in the latter it is continuous, elevated, and extensive. To this latter source we may therefore attribute the underground supply at Windsor Forest; and we may affirm with considerable confidence that under the Windsor district large supplies of excellent water might be obtained by borings carried out on a sufficient scale into the Lower Greensand, should the supply from the Chalk fail.

It is very probable that the Lower Greensand is altogether cut out by the ridge of Mesozoic or Palæozoic rocks, which may be presumed to extend under the Valley of the Thames at Windsor; for it will be recollected that in the Richmond boring there was a thickness of only 10 feet of this formation.[1]

Taking the district from Dorking to Selborne, the Lower Greensand has a range of nearly 30 miles from east to west, with a general dip towards the north and north-west, and an average exposed surface of 5 to 7 miles wide (as, for example, at Haslemere), giving an area of 150 to 180 square miles. As this formation is exceedingly open and porous, and is destitute of superficial covering, except the soil, the proportion of the rainfall that enters the rock and constitutes a permanent source of supply must be very large indeed; perhaps not less than two-thirds of a rainfall of about 28 inches, or 18·6 inches, sinks down into the beds, the remainder being evaporated. The ground occupied by the formation is very elevated, several points

[1] The magnetic survey of the British Isles, carried out by Profs. Rücker and Thorpe, indicates that between Windsor and Reading there exists 'a high peak' of old rocks rich in iron, and sending off ridges in the direction of Oxford towards the north-west, and Cambridge towards the north-east. In this locality the magnetic disturbance due to such concealed rocks is remarkable—causing a variation of the needle, both as regards dip and horizontal force, altogether unusual. This peak is overlain by the Chalk in the Valley of the Thames, but is probably sufficiently high (so to speak) to dissever the Lower Cretaceous beds of the south from those which reach the surface in Oxfordshire. See Phil. Trans. Roy. Soc. vol. clxxxiii. A (1890) p. 283.

Diagrammatic Section from the Thames Valley, below Maidenhead, to Haslemere.



[Distance = about 35 miles.]

5. Bagshot Sands.
4. Lower London Tertiaries.
3. Chalk and Upper Greensand.
2. Gault Clay.
1. Lower Greensand.

[*Note.*—The section exhibited at the meeting differed slightly from the above. I had the advantage of hearing the remarks of Mr. Whitaker in the course of the discussion, and he expressed the opinion that it was probable that the Gault was not interrupted by the Palæozoic ridge. The question is one which is entirely conjectural, but considering Mr. Whitaker's great knowledge of this subject, I thought it desirable to follow his view, and have altered the section accordingly.—January, 1894.]

reaching levels between 800 and 900 feet above Ordnance datum. For example, the broad plateau of Hindhead, south of Farnham, reaches an elevation of about 900 to 910 feet where crossed by one of the sections of the Geological Survey (Sheet 73); also at the Royal Huts Inn the surface rises to 840 feet, and at Gibbet Hill to 895 feet, according to the Ordnance Survey. The average level of this broad tract of Lower Greensand about Haslemere may be taken at about 600 feet, which is nearly 400 feet higher than the surface of the ground at the boring at New Lodge, Windsor; so that we can account for the great hydrostatic pressure of the water at this spot, notwithstanding the long distance that it has to travel through the mass of the formation itself. Doubtless the whole formation under the Chalk is waterlogged; but it should be recollected that when reached by a well or borehole the supply derived from the imprisoned water in the underground reservoir may gradually fall off, and the supply then becomes dependent on the annual percolation. This has been found to be the case with wells in the New Red Sandstone.

Discussion.

The President said it was satisfactory to learn that there was an area near West London in which the Lower Greensand was full of water. He thought that the section exhibited by the Author explained why it was full in that particular locality, for the rainfall about the extensive area of Hindhead, which lay nearly due south, must be considerable.

Mr. W. J. Lewis Abbott wished to ask if Prof. Hull had any absolute data upon which to bring up this Palæozoic ridge to within 200 feet of O.D., as shown in the section. He would be glad to know whether, in the boring, the Folkestone Beds showed any lithological change, such as would be expected, had that part of the beds been deposited along the shallow sea of a Palæozoic island-ridge. The extended outcrop of the Greensands was quite sufficient to account for their superior yield of water.

Mr. W. Whitaker also spoke.

The Author replied.

12. *On the* Rhætic *and some* Liassic Ostracoda *of* Britain. By Prof. T. Rupert Jones, F.R.S., F.G.S. (Read January 10th, 1894.)

[Plate IX.]

Contents.

I. Published Observations in Chronological Order.

The occurrence of small Ostracoda in the Rhætic strata of England has been known for about half a century, chiefly owing to the researches of the Rev. P. B. Brodie, F.G.S., who discovered them in the sections exposed at Wainlode, Westbury, Aust Passage, and elsewhere.

1842–1845.—The Wainlode section is on the south side of the Severn, about halfway between Tewkesbury and Gloucester, and 3 miles W.S.W. from Coomb Hill. It was briefly described by H. E. Strickland,[1] and more fully by the Rev. P. B. Brodie.[2] Since then the Geological Surveyors and others have studied it in further detail.[3]

This section shows:—

1, 2, 3. Black clay, limestone, and shale of the Lower Lias.

4 [Rhætic [4]]. Insect-bed or *Monotis*-bed, containing "*Cypris*, apparently identical with that which marks the yellow limestone (No. 6) below." ('Fossil Insects,' etc., p. 59.)

5. Clay.

6. "Hard, yellow, nodular limestone, with small shells like *Cyclas*, a species of *Unio*, Plants (*Naiades*), *Cypris*, and very rarely scales of Fish." (*Ibid.*)

7–14. Clays, shales, and Bone-bed.

"Mr. Strickland has found the yellow *Cypris*-limestone with *Cyclas* (?), the Pecten- and Bone-beds . . . at Dunhamstead, on the line of the Gloucester-and-Birmingham Railway, near the Droitwich Station" ('Fossil Insects,' etc., p. 72); and at Evesham "are traces of the *Ostrea*-bed [Lias] above and of the *Cypris*-bed and Plant-bed below" (*ibid.*).

Among the specimens kindly lent me by the Rev. P. B. Brodie, one piece of the '*Cypris*-bed,' from the Wainlode Cliff, is a hard, sandy limestone, containing a '*Pteromya*.'

[1] Proc. Geol. Soc. vol. iii. part ii. (1842) p. 586; *ibid.* vol. iv. part i. (1843) p. 18.

[2] Proc. Geol. Soc. vol. iv. part i. (1843) pp. 15, 16; and 'A History of the Fossil Insects in the Secondary Rocks of England,' 1845, pp. 58, 59.

[3] See H. B. Woodward's 'Geology of England and Wales,' 2nd edit. 1887, pp. 242–251.

[4] According to the arrangement adopted by the Geological Survey.

The Garden-Cliff section, near Westbury-on-Severn, 8 miles from Gloucester ('Fossil Insects,' etc., p. 79), has at the top—

1 [Lias]. *Ostrea*-bed.

2 [Rhætic]. Insect-limestone, with *Monotis decussata.*

3. Shale and clay.

4. "Hard, yellow, and grey limestone, often slaty and sandy, . . . with supposed *Cyclas*, Plants (*Naiades*), *Cypris*, and scales of Fish identical with those at Wainlode."

5. Shale and clay.

6. Bone-bed. This series is stated to be "more developed . . . a little further to the north." At p. 80 it is stated that "The Plants (*Naiadita lanceolata*) and *Cypris* are here much more abundant, the surface of the slaty portions being covered with remains of the latter Crustacean, which are collected together in masses of some thickness, just as we find them in many freshwater deposits. . . . We have [here] a new and highly interesting feature in the history of this deposit. . . ."[1]

The section at Aust Passage on the Severn, about 30 miles S.W. of Tortworth and 12 miles from Bristol ('Fossil Insects,' etc., p. 82), consists of :—

1. Rubble; 6 feet. 2 [Lias]. Oyster-bed, one of five beds of stone; 4 feet. 3. [Rhætic]. Landscape-stone; 5 feet. 4. Clay; 2 inches. 5. White stone: *Cypris*- and Plant-bed with *Cyclas*?; 6 feet. 6. Clay; 3 inches. Below this are the Pecten-bed with a clay and the Bone-bed.

At p. 102, *op. cit.*, the Rev. P. B. Brodie includes in his list of fossils :—

"*Cypris liassica* (Brod.), page 80 (*Cypris*-bed), Wainlode, Westbury, Bickmarsh, Bedminster,[2] Aust."

1848.—In 1848, H. G. Bronn ('Index Palæontologicus,' vol. i. p. 389) refers to "*Cypris liassica*, Brod. foss. ins. 80, 102 (an *Cytherinæ*, sp. ?)."

1854.—In 1854, J. Morris ('Catal. Brit. Foss.' 2nd edit. p. 104) refers *Cypris liassica* to "Brodie, Foss. Ins., p. 80. Lias. Wainlode."

1855. In the Mém. Soc. Géol. France, ser. 2, vol. v. part ii. p. 333, and pl. xxvi. fig. 12, O. Terquem figured and described an Ostracod as *Cypris liassica*, Brodie. But it does not correspond with any of our Rhætic forms, and was found in marine beds of the Lias in Luxemburg and the Department of the Moselle.

1861.—Mr. Charles Moore, after careful study of the Rhætic formation, noticed the occurrence of '*Cypris*' and '*Cypridæ*' in the White Lias of the Rhætic formation,[3] and particularly of a

[1] Mr. Brodie adds in a footnote to this passage :—'I propose to call the Cypris *Cypris liassica*, as it is the only one of the kind at present known in that formation' [then regarded as Lower Lias, but afterwards (1865) known as Rhætic].

[2] For C. Moore's notice of the section at Bedminster, near Bristol, see Quart. Journ. Geol. Soc. vol. xxiii. (1867) pp. 500, 501.

[3] *Op. cit.* vol. xvii. (1861) p. 496.

form which he referred to "*Cypris liassica*, Brodie," at Beer-Crowcombe, Stoke, Vallis, etc.[1]

The section at Beer-Crowcombe[2] shows:—

1 & 2. Some beds of the Lias, of and above the *Am. planorbis*-zone. 3. The Saurian Bed. 4 [Rhætic]. The White Lias. 5. The *Avicula-contorta*-zone. 6 [Trias]. The Keuper. No fossils are here especially mentioned.

One of the Ostracoda collected by C. Moore at Beer-Crowcombe has been kindly lent from the Bath Museum, through the courtesy of the Rev. H. H. Winwood, F.G.S.; it does not, however, correspond to the so-called *Cypris liassica*. About the occurrence of the latter (?) Mr. C. Moore states as follows[3]:—"The upper surfaces of the blocks of 'White Lias' in the sections near Taunton [Stoke St.-Mary, etc.] are frequently covered with the shells of this little Crustacean. The same conditions prevailed when the 'Flinty bed' at Beer-Crowcombe was deposited, as the shells are very numerous on its weathered surface. In the Vallis section it is very rare, and only represented by a single specimen, attached to a fragment of *Lima præcursor*."

1865.—The Rev. P. B. Brodie mentioned the occurrence of the *Cypris*-bed at Wootton Park, near Henley-in-Arden, in the Quart. Journ. Geol. Soc. vol. xxi. p. 160; and at p. 161 he expressed his opinion that this and the associated strata, below the Saurian Bed, would probably come "within the Rhætic series of the Trias."

1865.—Messrs. J. W. Salter and H. Woodward's 'Descriptive Catalogue of a Chart of Fossil Crustacea' contains figures of two 'Rhætic' (?) Ostracods from Somerset, enumerated at p. 21, as [fig.] "87, *Cythere liassica*, Jones, MS.," and "88, *Cythere*, sp. nov., Jones, MS." There is some confusion here, for the specific name given to fig. 87 is Brodie's, not Jones's; nor is it the '*Cypris liassica*,' but some form of *Cytheridea*. Fig. 88 is probably of the same species as that represented by fig. 6 in Pl. IX. Although the sketches for figs. 87 and 88 were supplied by me in 1865, all trace of them and of the specimens has been lost. These latter, however, may possibly have been found by me in some probably Lower-Liassic limestones near Taunton, Somerset.

1867.—Mr. C. Moore recorded the occurrence of '*Cythere liassica*' in the 'Rhætic White Lias' of the Camel Hill Railway-cutting[4] on the Westbury-and-Weymouth line. Mr. E. Wilson has remarked[5] that the fact of some of the whiter beds of the Lower Lias, as well as some of the Upper Rhætic, having both been termed 'White Lias,' leads to occasional confusion. He also informs me that Mr. C. Moore's 'List of Fossils' at p. 465, vol. xxiii. *op. cit.*, shows that it is a mixed series of Rhætic and Lower-Lias species; or it is

[1] Quart. Journ. Geol. Soc. vol. xvii. (1861) p. 514.
[2] *Ibid.* pp. 485, 486.
[3] *Ibid.* p. 512.
[4] Quart. Journ. Geol. Soc. vol. xxiii. (1867) p. 465.
[5] *Op. cit.* vol. xlvii. (1891) p. 546.

even possible that all the 'White Lias' here alluded to may belong to the Lower Lias.

Mr. Moore also mentions as occurring at the Willsbridge cutting on the Mangotsfield Railway,[1] "2 *b*. Laminated light-blue clay, with *Estheria minuta* [var. *Brodieana?*], *Cythere liassica*, *Avicula decussata*, etc.", lying on a representative of the well-known Landscape-stone. He further remarks[2]:—"The surface of the laminated clay (2 *b*) is often entirely covered by *Cythere liassica*, the specimens being generally so uniformly arranged lengthwise as to show the direction of the current of the water by which they were last washed."

1876.—In that part of R. Tate and J. F. Blake's work on the 'Yorkshire Lias' which treats of the Crustacea, the Rev. J. F. Blake describes and figures a really Liassic Ostracod (p. 430, pl. xvii. fig. 1) as '*Bairdia liassica*, Brodie, sp.', which belongs to a different genus (probably *Cytheridea*). It is not like Brodie's '*Cypris liassica*,' referred to above, and of which a labelled specimen is preserved in the Geological Society's Collection. Nor does it agree with M. Terquem's description and figures of Terquem's *Cypris liassica*[3] from the Lower Lias of Zetrich, Halberstadt, Metz, and Jamoigne, which is probably a *Cytheridea*, and included in Mr. Blake's synonyms (*op. cit.* p. 430). In the same list, "1872, *Bairdia* [?] *ellipsoidea* [G. S. Brady, MS.], Jones, Quart. Journ. Geol. Soc. vol. xxviii. p. 146," with a slightly modified description of the latter, and with some additions, is used for the *Bairdia liassica*, *loc. cit.*

1877.—H. Woodward, in his 'Catalogue of British Fossil Crustacea,' p. 102, refers to "*Cythere liassica*, Brodie, sp., 1845, Rhætic; Wainlode, Severn."

II. Named Specimens.

Of authentically named specimens of Brodie's '*Cypris liassica*' I can find only one or two good examples in the Geological Society's Collection; but none in the British Museum (Natural History), nor in the Museum of Practical Geology. Nor is there a good published figure of that species.

Other hand-specimens, with Ostracods incorrectly named '*liassica*,' are also here enumerated.

I. In the Geological Society's Collection, at Burlington House, are some specimens of cream-coloured limestone full of obscure plant-remains, and bearing a few indications of a small Ostracod. These are labelled: "*Naiadites acuminata*, Buckm., Geol. Chelt., p. 93; Rhætic; Bristol; *Cypris liassica*, Brodie. Rev. P. B. Brodie, F.G.S."

The above-mentioned specimens exactly correspond in aspect and

[1] Quart. Journ. Geol. Soc. vol. xxiii. (1867) p. 498. [2] *Ibid.* p. 499.
[3] Mém. Soc. Géol. France, ser. 2, vol. v. part ii. (1855) p. 333, pl. xxvi. figs. 12 *a*, *b*, *c*.

contents to some pieces of Rhætic limestone from Pylle Hill, near Bristol, sent to me by Mr. E. Wilson, F.G.S., in 1891, and noticed by him in Quart. Journ. Geol. Soc. vol. xlvii. (1891) pp. 545–549. They are similar also to a specimen from Uphill, near Weston-super-Mare, collected by Mr. C. Moore, and now in the Bath Museum.

In the Geological Society's Collection there are also three pieces of the "*Cypris*-bed with traces of small plants; Westbury. Mr. Brodie." One piece shows an edge-view of what seems to be an internal cast of *Darwinula liassica*.

In one of the drawers of the Collection is an old label purporting to be a "List of fossils from the Lower Lias of Gloucestershire:—

"Insects, Wainlodes Cliff.

"Insect-limestone and *Cypris*-bed, Wainlodes.

"Insect-limestone and *Cypris*-bed, Westbury, and minute plants."

These above-mentioned specimens may well have been those presented by the Rev. Mr. Brodie in 1842 [1] as "Remains of Insects and other fossils from the Lower Lias [Rhætic ?] near Cheltenham" [and elsewhere?].

II. The specimens lent from the Charles-Moore Collection in the Bath Museum in 1892–93 (see above, p. 158) comprised:—

1. "*Cypris liassica.* Rhætic Beds. Beer-Crowcombe." Consisting of numerous small, oval, black, smooth Ostracoda (*Cytheridea*, see Pl. IX. fig. 7), lying close together in a hard, grey marl.

2. "*Cypris liassica* (slab covered with). White Lias near Taunton." A buff-coloured limestone, with numerous small, oval, smooth Ostracoda, not so well preserved as in the grey-marl specimen, but apparently belonging to the same species. They lie on a bed-plane, together with fragments of shells (*Pecten*) and a piece of an Echinid spine; also the cast of a small furrow or trail. These are evidently not Brodie's species; but Mr. C. Moore seems to have met with the real form elsewhere, judging from his remark that on some bed-planes at the Willsbridge cutting (see above, p. 159) the carapace-valves lie uniformly lengthwise, as if they had a relatively long axial diameter, as is the case with *Darwinula liassica*.

3. A piece of cream-coloured limestone, containing fragments of *Naiadita* and valves of *Darwinula liassica*, from Uphill, near Weston-super-Mare, Somerset.

4. Some mounted Ostracoda, labelled "*Bairdia liassica*, Brodie; Lower Lias; Brocastle," belong to the genus *Cytheridea* most probably; and are really Lower-Liassic, not Rhætic.

III. The Rev. P. B. Brodie has kindly given me several interesting specimens from his Collection, but only one of them yields a form identical with his '*Cypris liassica*'; and there are other forms, of much interest, which will be noticed in the sequel.

IV. It is Mr. Edward Wilson's large series of shale and limestone (from Pylle Hill, Bristol), alluded to in Quart. Journ. Geol.

[1] Proc. Geol. Soc. vol. iv. part i. p. 50.

Soc. vol. xlvii. (1891) p. 548, that supplies us with the best material illustrating the particular Ostracodous forms under notice.

Old exposures at Bedminster, near Bristol (Mr. Wilson informs me), may have been a source for *Darwinula liassica* in former times, for the same limestone as that occurring at Pylle Hill is evidently referred to by the late Mr. W. W. Stoddard in his essay on the Geology of the Bristol Coal-field, part v., in the Proc. Bristol Nat. Soc. n. s. vol. ii. part 3 (1879), pp. 280, 281, where he states: "Immediately on leaving Bedminster we notice, on the left-hand side of the road and just under the reservoir, a small well, on the top of which is a thin bed of light cream-coloured limestone full of remains. . . . of *Naiadites petiolata*," . . . and "valves of *Estheriæ* and *Cytheridæ*. Near, and behind a public-house, is a small quarry in which is a whitish cream-coloured bed containing . . . valves of *Cytheridæ* in . . . abundance . . . . Eighteen inches above this is the well-known Cotham marble" with Insects and Landscape-stone. Remains of Insects and Entomostraca were found in a bed about 15 inches above the Cotham marble. Of the beds in this little quarry Mr. Stoddard gives a detailed section, and Mr. Wilson refers them to a higher zone than the *Naiadites*-bed above mentioned, which he correlates with the Upper-Rhætic bed '*l*' of his Pylle Hill section. He thinks that, in Mr. Stoddard's section of the quarry, beds nos. 1–5 (21 inches thick) above the Cotham marble belong to the Lower Lias, and beds 6–10 (21 inches of thin clays and limestones) to the Upper Rhætic. The strata above the Cotham marble here are said by Mr. Stoddard to comprise a bed with *Monotis decussata* and fish-remains (and indistinguishable from that at Garden Cliff, near Westbury-on-Severn), overlying the bed (no. 3) with Insects. These beds are referred to the Rhætic series above, at p. 156, in accordance with the classification adopted by the Geological Survey.

Mr. Wilson informs me that in the roadside quarry on Bedminster Down, a little beyond the public-house referred to above, there are now exposed beneath the Cotham marble 2 to 3 feet of shales precisely similar to bed '*m*' of his Pylle Hill section, without any hard beds in them.

V. Mr. William Cunnington, F.G.S., gave me some years ago a few specimens in bluish shale from Bedminster,[1] which prove to be *D. liassica*.

Another interesting specimen from Mr. Cunnington's Collection is a piece of greenish-grey argillaceous limestone, bearing, on a bed-plane, a multitude of individuals of *Darwinula liassica*, lying in an almost uniformly parallel arrangement, caused by the moving water in which they were left. This is marked 'Clifton' and (incorrectly) 'Mountain-limestone.' Mr. E. Wilson, F.G.S., having examined the specimen, states that it belongs probably to his 'Upper-Rhætic' Series, "perhaps a hard seam in the light greenish-blue shales marked '*m*' in the Pylle Hill section" given by him in Quart.

[1] This may be the same, perhaps, as that referred to by Mr. E. Wilson, F.G.S., in Proc. Geol. Assoc. vol. xiii. (1893) p. 129.

Journ. Geol. Soc. vol. xlvii. p. 546. The footnote at that page refers to the late Mr. Tawney's section of the Rhætic beds at Oakfield Road, Clifton, where they are faulted down into the Keuper area; and Mr. Wilson thinks that the specimen under notice may have come from that excavation.[1]

Other possible sources for it, he says, may be the exposures at Cotham, Pylle Hill, and Bedminster; but these localities could not have been termed 'Clifton.'

VI. We must not omit to state that from Linksfield, near Elgin, in Morayshire, Scotland, many years since, specimens of some similar Rhætic Ostracoda were supplied by Mr. Patrick Duff, Mr. S. H. Beckles, and Mr. Charles Moore, as fully acknowledged in the Monogr. Foss. Estheriæ, Pal. Soc. 1862, p. 75.

III. Description of the Species.[2]

1. Darwinula liassica (Brodie). (Pl. IX. figs. 1 *a*, 1 *b*, 1 *c*.)

	Length.	Height.	Thickness of carapace.
Fig. 1 *a*	·85	·35	— mm.
Fig. 1 *b*	·7	·3	— mm.
Fig. 1 *c*	·65	—	·35 mm.

Carapace sub-cylindrical or sub-reniform, varying in outline with slight differences probably due to either individual or sexual growth. The dorsal edge is more or less arched; and the ventral is somewhat hollowed, and more or less sinuous. The ends are rounded; but the front end has rather smaller dimensions than the other. Surface smooth.

The left valve overlaps the right along the back, but in some individuals unequal pressure gives rise to a different appearance.

The original amount of convexity of the surface can seldom be estimated, on account of the crushed condition of many specimens, the partial embedment of others, and the rarity of exposed edge-views. The carapace, however, is convex along the middle, and thickest at the posterior third (fig. 1 *c*).

Some exposed interiors show very simple edges, always somewhat broken.

With regard to other known species of *Darwinula*, it is to be noticed that, of several published figures of the small Ostracoda referable to *D. leguminella*[3] (E. Forbes), none exactly agree in proportions with *D. liassica* (Brodie); and it differs also from *D. Stevensoni*, Brady and Robertson,[4] especially in being less compressed anteriorly.

[1] [In this specimen from Clifton several slightly different forms of *Darwinula liassica* are recognizable; and indeed one relatively short form may prove to be specifically distinct.—Feb. 17th, 1894.]

[2] I have to acknowledge Mr. Frederick Chapman's kind help in preparing and sketching most of the Ostracoda here described.

[3] In the Monogr. Foss. Estheriæ, Appendix, 1862, pl. v. fig. 31; Quart. Journ. Geol. Soc. vol. xli. (1885) pl. viii. fig. 30; Geol. Mag. 1886, pl. iv. fig. 4.

[4] Ann. Mag. Nat. Hist. 1870, and elsewhere, 1874 and 1889.

Specimens of this species in the Geological Society's Collection came from the cream-coloured limestone with *Naiadites*, or '*Cypris*-bed,' at Westbury-on-Severn (see p. 157); and from a locality at 'Bristol,' which, from Mr. Brodie's information, appears to have been on the Wells Road.[1] These are similar to Mr. Wilson's limestones '*i*' and '*l*' at Pylle Hill, from which figs. 1 and 2 have been taken. The shale '*m*' also contains this species in abundance.

It occurs in a shale from Bedminster (p. 161), probably the same as some Rhætic shale which Mr. Wilson has found in a quarry on Bedminster Down,[2] over a mile west of Pylle Hill.

[It is present in the hard calcareous shale from the excavation at Clifton (p. 162).—February 17th, 1894.]

Also in a dark-grey, probably Rhætic shale 'above the Insect-limestone' in the Wainlode section (P. B. Brodie).

A limestone, similar to that of Pylle Hill, with *D. liassica* and *Naiadites*, is in the Charles-Moore Collection, Bath Museum, from Uphill, near Weston-super-Mare (see p. 160).

1*. Darwinula liassica (Brodie), var. major, nov. (Pl. IX. fig. 2.)

Length.	Height.
1 mm.	·55 mm.

The valve in this variety is much larger than what appears to be the normal form; the extremities are more unequal in size, and the anterior is definitely smaller than the other end. (See fig. 1 *b*.)

This variety occurs, in company with the smaller valves (but rarely) in the light-blue shales of Pylle Hill ('*m*', E. Wilson), in that of Bedminster, and in the shale 'above the Insect-limestone' at Wainlode Cliff (Brodie). [Also in Mr. Cunnington's specimen from Clifton.—Feb. 17th, 1894.]

2. Darwinula globosa (Duff). (Pl. IX. figs. 3, 4 *a*, 4 *b*.)

Cypris globosa, Duff, 'Sketch of the Geology of Moray,' 1842, p. 16 and p. 19.

Candona? globosa, Jones, Monogr. Foss. Estheriæ, Pal. Soc. Appendix, 1862, pp. 126, 127, pl. v. figs. 23 and 24.

	Length.	Height.
Fig. 3	·95	·45 mm.
Fig. 4 *a*	·95	·4 mm.

"Carapace subcylindrical, smooth; carapace-valves oblong, straight on the ventral edge, slightly arched on the dorsal, rounded at the ends, but obliquely at the antero-dorsal region, so that the fore end is narrower than the other." The lucid spots (muscle-marks) are not so much like those of *Candona Forbesii* (Monogr. Tertiary

[1] Mr. Wilson tells me that the exposure here may have been the old Pylle-Hill section, abutting on that road.

[2] Proc. Geol. Assoc. vol. xiii. (1893) p. 129.

[illegible]

[illegible]

above, p. 160), in the Charles-Moore Collection, Bath Museum, labelled '*Cypris liassica*.' This is, however, quite different from that form, and probably came from the Lias of the locality mentioned.[1]

Being sufficiently distinct, it may be appropriately named after its discoverer, who devoted much time and labour to the study of the Lias and Rhætic beds.

Numerous individuals having the same shape, but not dark-coloured, crowd the bed-plane and constitute a small thickness of a piece of yellowish limestone, from Long Itchington in Warwickshire (collected by the Rev. P. B. Brodie some time ago).

With *Cytherideæ* having this subtrigonal character we can associate the form described and figured by Terquem as *Cypris liassica* in 1855 (see above, p. 159); also Salter and Woodward's fig. 87, '*Cythere liassica*,' 1865 (see above, p. 158).

5. Cytheridea, sp. (indeterminable). (Pl. IX. fig. 9.)

Length.	Height.
1·3 mm.	·9 mm.

This seems to be the right valve of a large, smooth *Cytheridea*, but it is not sufficiently exposed from the matrix for definite determination. It occurs in a small piece of compact yellowish limestone, collected by the Rev. P. B. Brodie some years since, and labelled 'Bristol.' The matrix is not like any of the known Rhætic limestones of that locality, and it may have come from some neighbouring exposure of the Lower Lias.

6. Cythere reticostata, sp. nov. (Pl. IX. fig. 10.)

Length.	Height.
1·25? mm.	·7 mm.

This is a fine, strong, obliquely-subquadrate valve. The front edge slopes from the antero-ventral corner to the anterior hinge, and bears a thickened edge, which dies out along the oblique dorsal margin before reaching the contracted and rounded hinder extremity. The ventral margin is also oblique, and nearly straight as far as can be seen. The surface is ornamented with a row of pits within the anterior border, accompanied with parallel ridges, which, passing along the dorsal region, are connected by an open meshwork; and this appears to become rather looser and less marked on the rest of the surface, as far as exposed.

This kind of ornament is not unusual among the *Cytheridæ*. Both for shape, partially, and the arrangement of riblets and reticulation, some resemblance is noticeable in *Cythere septentrionalis*, Brady.[2]

[1] For the section, see Quart. Journ. Geol. Soc. vol. xvii. (1861) pp. 485, 486.

[2] Trans. Zool. Soc. vol. v. (1866) pl. lx. fig. 4; and Trans. Roy. Dubl. Soc. ser. 2, vol. iv. (1889) pl. xvi. fig. 13.

The specimen under notice is in a friable cream-coloured limestone full of Ostracoda (*Cytheræ?*) and without *Naiadites*, from the Rev. P. B. Brodie's Collection, labelled 'White Lias, Bristol.' Figs. 11 and 12 accompany it. Collected some years ago, it was probably from one of the whitish beds of the Lower Lias somewhere near Bristol, perhaps at Bedminster.

7. Cythere Wilsoni, sp. nov. (Pl. IX. figs. 11 *a*, 11 *b*, 11 *c*.)

	Length.	Height.	Thickness of carapace.
Fig. 11 *a*	1·2	·75	— mm.
Fig. 11 *b*	1·25	—	·6 mm.
Fig. 11 *c*	—	·8	·6 mm.

Carapace suboblong, smooth, elliptically rounded in front, smaller and more symmetrically rounded behind. Anterior hinge well marked; dorsal edge rather oblique, and curving at the lower hinge to meet the narrow end of the valve; ventral edge somewhat sinuous, projecting a little at the front third (fig. 11 *a*), but slightly incurved behind it, and deeply sunken along the junction of the valves (figs. 11 *b*, 11 *c*). Edge view, subacute-oval; end view, obcordate.

This is abundant in the piece of friable limestone which also contains figs. 10 and 12. Collected, and formerly labelled 'White Lias, Bristol,' by the Rev. P. B. Brodie. Probably not from the Rhætic White Lias, but really Liassic. I name it in honour of Mr. Edward Wilson, F.G.S., whose researches in the geology of Bristol and its vicinity are well known, and who has obliged me with much valuable information whilst preparing this notice of the local Ostracoda.

8. Cythere, sp.? (Pl. IX. fig. 12.)

Length.	Height.	Thickness of carapace.
1·7 mm.	—	·75 mm.

The dorsal aspect of an embedded carapace of a *Cythere* is here seen, such as fig. 11 would probably possess if it were of a larger size. The left valve is broken at each end; but the right valve, excepting that the hinder hinge has been chipped out, shows a perfect dorsal aspect.

It is in the friable whitish limestone labelled 'White Lias, Bristol;' probably Liassic, not Rhætic. Collected by Mr. Brodie.

9. Cytheropteron Brodiei, sp. nov. (Pl. IX. figs. 13 *a*, 13 *b*, 13 *c*, 13 *d*.)

	Length.	Height.	Thickness of carapace.
Fig. 13 *a*	·6	·45	— mm.
Fig. 13 *b*	·6	—	— mm.
Fig. 13 *c*	·6	—	·4 mm.
Fig. 13 *d* ...	—	·375	·45 mm.

This is a small, somewhat peachstone-shaped Ostracod, probably a *Cytheropteron*, judging by its shape, more especially of that division of the genus embracing the *C. concentricum*, var. *virginea*, J.[1] (of the Chalk), and the recent *C. depressum* and *C. læve*, B. & N.[2] The specimen under notice, however, though very small, is relatively much fuller and more nearly rotund than the recent forms.

The carapace in side view is nearly oval, but subacute in front, and quite sharp behind. The back has a semicircular curve and a sharp edge. The ventral margin is broad, arcuate in profile, and deeply sunken along its centre, where the edges in meeting make a slight ridge within an inverted arch. The edge view is acute-oval; the end view trigonal and broadly obcordate.

This little fossil Ostracod has a distant resemblance to the carapace of a *Metacypris* in some points as to shape, but its relationship to *Cytheropteron* is much closer.

It is probably Liassic, occurring with figs. 10, 11, and 12, and is here named after the enthusiastic veteran geologist, my respected friend, the Rev. P. B. Brodie, F.G.S., who collected the specimen many years ago somewhere in the Bristol district.

EXPLANATION OF PLATE IX.

(The figures are all magnified 20 diameters.)

Fig. 1. *Darwinula liassica* (Brodie). *a*, right valve, large individual; *b*, right valve, small individual; *c*, edge view of carapace. Pylle Hill, Bristol.

Fig. 2. *Darwinula liassica* (Brodie), var. *major*, nov. Left valve. Pylle Hill.

Fig. 3. *Darwinula globosa* (Duff). Left valve. Linksfield.

Fig. 4. *Darwinula globosa* (Duff). *a*, left valve; *b*, muscle-spot. Linksfield.

Fig. 5. *Darwinula globosa* (Duff), var. *stricta*, nov. Left valve. Linksfield.

Fig. 6. *Cytheridea ellipsoidea* (Jones). *a*, left valve; *b*, right valve; *c*, dorsal view of carapace. Westbury-on-Severn?

Fig. 7. *Cytheridea Moorei*, sp. nov. *a*, right valve; *b*, left valve; *c*, edge view of carapace. Beer-Crowcombe, Somerset.

Fig. 8. *Cytheridea Moorei*, sp. nov. *a*, left valve; *b*, edge view of carapace. Long Itchington, Warwickshire.

Fig. 9. *Cytheridea*, sp. Right valve. Near Bristol.

Fig. 10. *Cythere reticostata*, sp. nov. Right valve, imperfect. Near Bristol

Fig. 11. *Cythere Wilsoni*, sp. nov. *a*, left valve; *b*, ventral aspect of carapace; *c*, end view of carapace. Near Bristol.

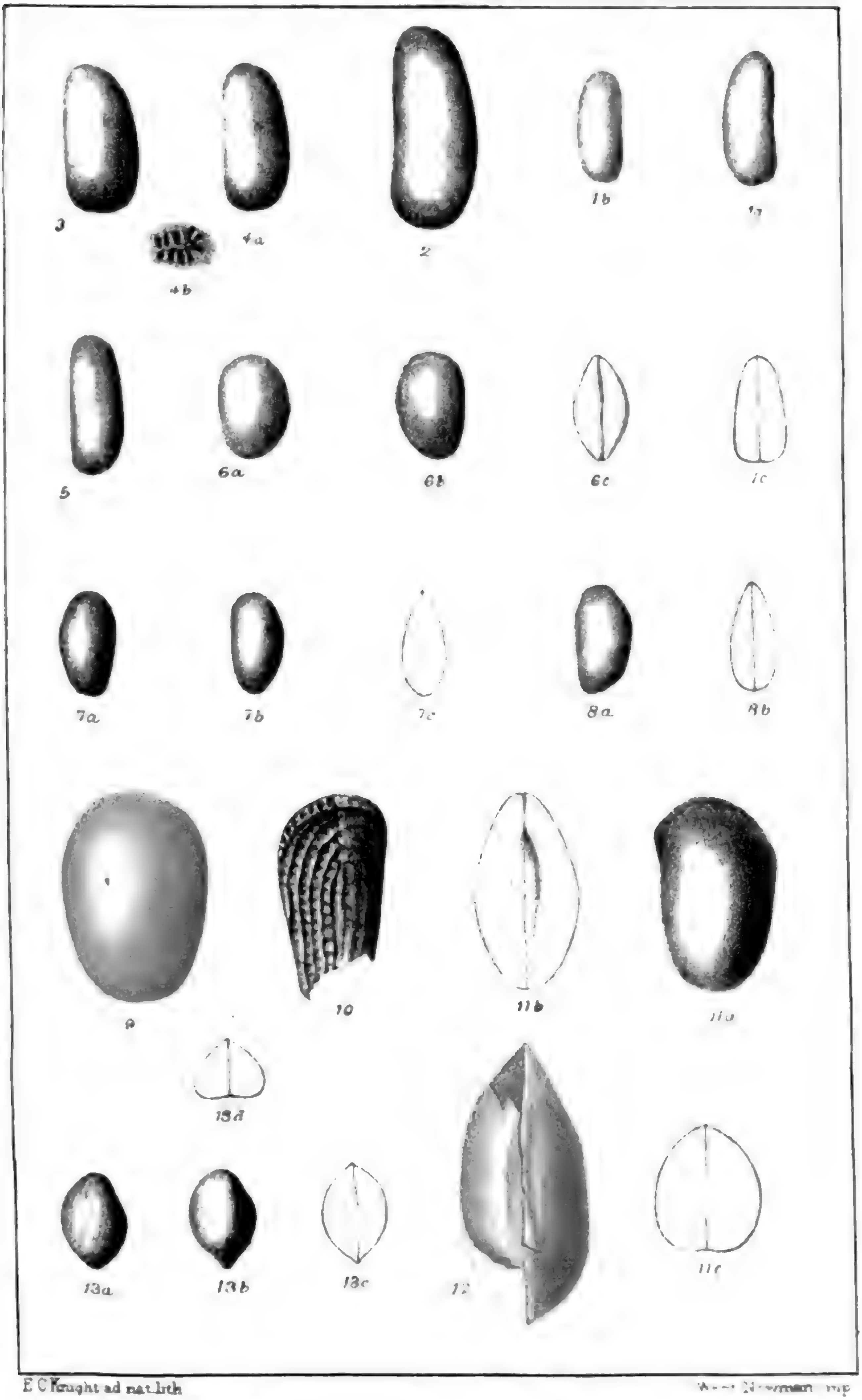
Fig. 12. *Cythere*, sp. Dorsal view of carapace, not quite perfect. Near Bristol.

Fig. 13. *Cytheropteron Brodiei*, sp. nov. *a*, carapace showing right valve; *b*, carapace placed obliquely, with the right valve uppermost; *c*, dorsal aspect of carapace; *d*, end view of carapace. Near Bristol.

Discussion.

The President complimented the Author on this further addition to the history of the Ostracoda, so many of his papers on this subject having already enriched the Quarterly Journal. The

[1] Suppl Monogr. Cret. Entom., Pal. Soc. 1890, p. 31, pl. ii. figs. 14–17.
[2] Trans. Roy. Dubl. Soc. ser. 2, vol. iv. (1889) pp. 210, 218, etc.



E. C. Knight ad nat. lith.

RHÆTIC & LIASSIC OSTRACODA.

present paper was of particular interest as giving a critical *résumé* of the present state of our knowledge, which it appeared was very much needed, in addition to his other work. It would be desirable to know how far the study of the Ostracoda throws any material light upon the change between Rhætic and Lias, and whether the separation was sharp or not. He also alluded to the difference of opinion between Mr. Horace B. Woodward and Mr. Edw. Wilson as to where the line should be drawn.

Dr. Henry Woodward also spoke.

The Author, in reply to the President's question,—whether the Ostracoda served to decide where the line of junction between the Rhætic and the Lower Lias actually occurs,—stated that in Mr. Wilson's 'Upper-Rhætic' beds *Darwinula liassica* (Brodie) abounds, and indicates either freshwater or brackish-water conditions; also at Westbury-on-Severn. Some sections near Bristol (localities not well defined) have shown, above these beds, which contain plant-remains (*Naiadites*), limestones with *Cytheridea*, estuarine or marine, and *Cythere*, a marine genus. This succession shows that the 'Rhætic White Lias' (Wilson) passed up into the other 'White Lias' above, by one or more passage-beds, probably included by the Geological Survey in the 'Rhætic' series. The habits and conditions of recent forms of the recognized genera supply the data for determining the probable habits of the fossil species.

13. *On the* Discovery *of* Molluscs *in the* Upper Keuper *at* Shrewley *in* Warwickshire. By the Rev. P. B. Brodie, M.A., F.G.S. (Read March 7th, 1894.)

Additional interest attaches to the green gritty marls containing remains of Cestraciont fishes at Shrewley, lately described in my paper read before this Society,[1] owing to the recent discovery of lamellibranch molluscs at that place. Mr. E. P. Richards, a young geologist, while we were working together at the quarry, drew my attention to an impression that he had just found. Though only a mould, I felt certain that it must have belonged to a shell of some kind, and that it was something quite new in the British New Red Sandstone, and therefore of some value. On a later visit I obtained several specimens belonging apparently to more than one genus. I sent my collection, amounting to fourteen specimens, to my friend Mr. R. B. Newton, of the British Museum (Natural History), and I requested Mr. Richards also to forward his to the same gentleman. In consequence of this, Mr. Newton read a short paper at the meeting of the British Association at Nottingham about them, and he recognized three apparently marine forms, belonging, as he thinks, to three distinct genera.[2]

As Mr. Newton points out, up to the present time, this is the only record of any true shells being found in the Keuper in this country, and this fact renders the discovery of greater interest and importance.

A shell resembling a *Modiola* was said, on good authority, to have been met with in the Upper Keuper at Pendock, in Worcestershire, many years ago, but it cannot now be found, and no further account was given of it. The matrix at Shrewley Quarry is unfortunately most unfavourable for the preservation of testacea, and it was very difficult therefore to determine those now, for the first time, detected in the New Red Sandstone in Britain.

The shells are fairly abundant, and they occur as far as can be ascertained at one end of the section, just above the red marl at the base, though they may be present in the same position elsewhere, and if the green marls could be got at, which cannot now be done, other and better specimens might be secured. Mr. Newton proposes to describe them in more detail and to give figures of the best examples.

Discussion.

Mr. R. B. Newton referred to the indebtedness of the Society to Mr. Brodie for his various communications on the Keuper of Warwickshire. The specimens found by him and by Mr. Richards were obscure impressions of lamellibranch shells, three of which he (the speaker) had selected for detailed description. The discovery of true marine fossils in the Shrewley Keuper was of the utmost importance, and the Author therefore deserved the thanks of geologists.

[1] Quart. Journ. Geol. Soc. vol. xlix. (1893) p. 171. [2] Geol. Mag. 1893, p. 557.

14. *The* Ossiferous Fissures *in the* Valley *of the* Shode, *near* Ightham, Kent.

By W. J. Lewis Abbott, Esq., F.G.S. (Read January 24th, 1894.)

Contents.

I. Introduction.

Doubtless there are many geologists in common with myself who have recognized the fact that, if the surface of the Wealden area has been subject to the oscillations claimed for it, then, considering the unyielding nature of the lime- and sandstones, we ought to find innumerable fissures, and by the law of chances these ought sometimes to occur in positions favourable to the preservation of those heterogeneous collections of objects that find their way into the drainers of a country. There are few, perhaps, who realize what a motley group of curiosities are to be found in large streams, unless they have spent some considerable time in walking between the tide-marks of a river in its lower reaches. It is not often conceived how large a portion of the life of to-day could be rescued from such a wreck. Here may be found bones of animals by the cartload, and the hard parts and fruit of vegetation, both terrestrial and aquatic. The principal non-marine mollusca are also represented, although the majority of shells are usually of aquatic species. To appreciate the profusion of these relics one need only travel for the same period over land-surfaces and note the difference of the result. I have frequently paced scores of miles over fields, foot by foot, chiefly in search of implements, without finding a single bone of an animal of either terrestrial or aquatic habits.

It is extremely important to bear these two conditions in mind when we try to account for the filling of fissures and caves with the materials that we now find in them. I have thought it absolutely necessary to draw attention to these important facts, because I regret that I am obliged to differ in opinion from so great an authority as Prof. Prestwich as to the manner in which caves and fissures have been filled. The successive faunas of the various strata, their stalagmitic sealing-down, the identity of the contents of fissures with river-débris, and their total dissimilarity to ordinary land-wash, together with other collateral characteristic features, to my mind render these deposits incapable of being the result of a *marine immersion*.

Unfortunately, the literature of the Weald would not encourage

one to expect very much from the Kentish fissures; it is true that references to the ossiferous 'pipes' date as far back as the classic days of Buckland,[1] but from his time to that of Prof. Boyd Dawkins only 7 species of vertebrates have been recorded, and 5 species of mollusca. I have visited a number of these pipes in the neighbourhood of Maidstone and the Shode Valley, and have no hesitation in saying that they are altogether of a different nature from the fissures which will be described in the following pages. The former are surface-deposits, pure and simple, irrespective of the various depths and extensions to which they have cut into the underlying strata, bones and implements being distributed through them exactly as in an ordinary brick-earth.

II. Fissures in the South-east of England: History of the Shode Valley.

Fissures abound in the hard strata of the Wealden district[2] from the North to the South Downs inclusive; at times they are mere empty cracks, never having been brought into direct contact with either the surface itself or even surface-waters. At others they open more or less distinctly above, sufficiently to admit of being filled with land-wash or blown sand; or a river gets access to them and carries in and deposits its suspended material, or its flotsam and jetsam. Again, they are occasionally wide enough to admit of human habitation, some now containing tons of the relics of human occupation, terminating in the midden period. There are yet others which, so far as we can see, have never been open at the surface: their presence has only been revealed by the denuding action of rivers in excavating their channels into the rocks in which the fissures have existed, and, after having thus broken into their secret chambers, the rivers have deposited within them those heterogeneous masses characteristic of the burdens of a stream. At times situation has favoured an entire filling of the fissures; at others the height to which they are filled marks the limit of the power of the flood-waters at a particular period in the valley's history, leaving an empty chamber above. Into this latter meteoric waters subsequently enter, which, percolating through the limestone and hassock, dissolve out part of the lime, not only of the rocks, but of the bones, and redeposit it all over the chamber and for a certain distance into the fissure-deposit, in the various forms of arragonite, flos ferri, stalagmite, and stalactite, until at last the contents of the fissure become sealed down. In some other cases,

[1] These pipes are described by W. Topley, F.R.S., in his memoir on 'The Geology of the Weald,' 1875, pp. 181–184. That author also gives copious bibliographic references to the subject, to which the reader is hereby referred in order to save repetition.

[2] I unsuccessfully worked a number of these before I located those here described, but upon enquiry I found that Mr. B. Harrison had already obtained bones from the latter, which he very kindly passed on to me, giving me at the same time an introduction to the quarry-owner. The latter has also taken great interest in my work, and kindly allowed his men to wheel away the débris for me, a service for which I am greatly indebted to him.

where the fissures appear to have maintained a free surface-communication through practically the whole of their history, very nearly all the bones are dissolved out, and the lime is redeposited in the interstices of the filling and the adjacent rocks, like veins in serpentine.

The description of the fissures near Ightham may be taken as a supplement or continuation of the paper by Prof. Prestwich on the drifts around that place.[1] It will, therefore, be unnecessary to recapitulate the description of the Shode,[2] upon whose banks these fissures occur; suffice to say that the stream now rises on the lower part of the face of the Chalk escarpment, about 1½ mile above Ightham, and after flowing over the Folkestone Beds in a general southerly direction, and receiving a westward branch, pierces the Hythe Beds in a picturesque gorge about 80 feet deep. It then winds round more to the east, and in about a quarter of a mile receives a tributary coming down from the N.E., past Borough Green. This latter stream has also carved out a deep valley, which, in wet weather, still carries water. A road has been cut into and along the old valley, exposing the old sandy brick-earth, the composition of which is very significant, owing to its similarity to the fissure-deposit. It also carries boulders of Ightham stone, chert, flint, and a few bones and other fossils.

In about another quarter of a mile the Shode receives a second branch from the N.E., thus leaving the area between the two tributaries as a promontory, which, by the approach of the two streams to each other and the rise of the Greensand escarpment or counterscarp, is more completely isolated. In this the fissures now to be described occur. The Shode then continues its southerly course through the Plaxtol gap till it joins the Medway. Prof. Prestwich, in his graphic description of this river,[3] gives a map and four transverse sections, which are indispensable in the study of this district. But to fully understand the exact condition of things, attention had better first be centred on a section (see fig. 1, p. 174) from the Chalk escarpment up the counterscarp to Shingle Hill. Here we see the Gault, estimated at 150 to 200 feet,[4] rising up from below the Chalk on the lower part of the face of the escarpment, stretching over and forming the low part of the Holmesdale Valley; from beneath this rise the Folkestone Beds, about 110 feet[5] thick; these follow up the dip-slope of the counterscarp till they reach Bitchet

[1] Quart. Journ. Geol. Soc. vol. xlv. (1889) pp. 270–294.

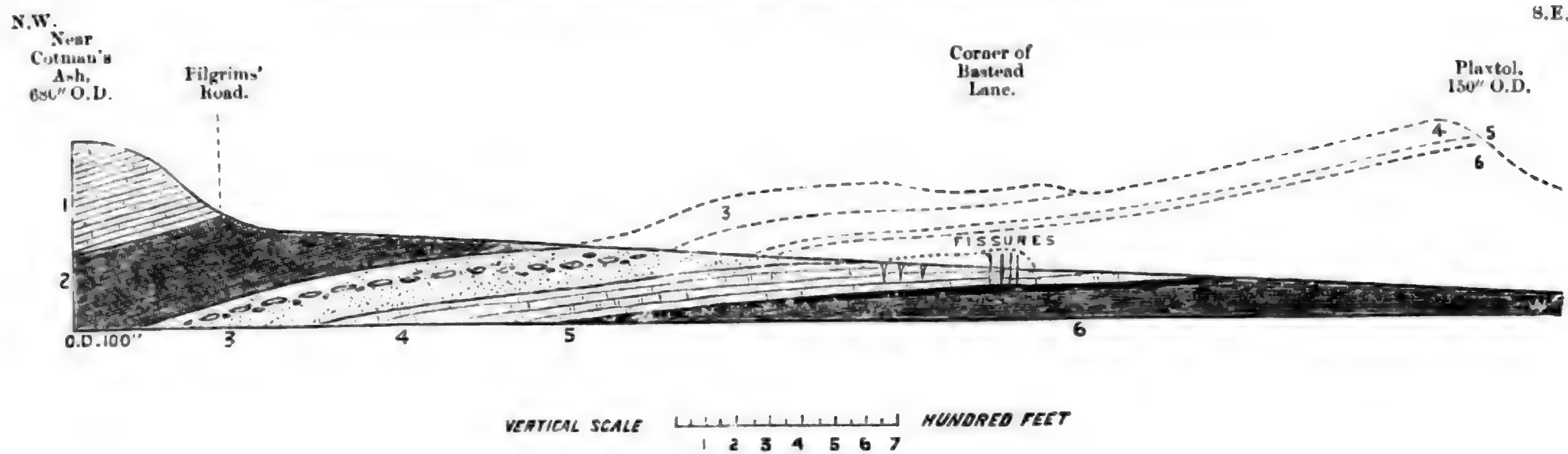
[2] Mr. Topley calls this stream the Plaxtole brook, *op. supra cit.* pp. 185, 289. About Plaxtol it is called the Bourne.

[3] *Op. supra cit.* pl. ix. & p. 272.

[4] In 'The Water-bearing Strata of London,' p. 90, Prof. Prestwich refers to a well at Wrotham which gave 120 feet of Gault. Mr. Topley informs me that the thickness of the Gault in this district is greater than was formerly supposed. A well at Shoreham Place gave 226 feet. He estimates the clay in the line of section at a little over 200 feet.

[5] These figures and measurements are all estimated from sections in the neighbourhood and from the table given by Mr. Topley in his Wealden memoir, plate iii.

Fig. 3.—*Section from near Cotman's Ash along the Valley of the Shode to Plaxtol.*



1. Chalk.
2. Gault.
3. Folkestone Beds.
4. Hythe Beds.
5. Atherfield Clay.
6. Weald Clay.

Green, by which time their upturned edges are cut through, thus exposing the underlying Hythe Beds, estimated not to exceed 100 feet. The latter are also much denuded, and a few hundred yards east of the section are cut through to the underlying Atherfield Clay, the thickness of which is estimated at 27 feet. Both the last-named beds appear on the face of the escarpment, where the Atherfield Clay is underlain by the Weald Clay.

The altitude at which the Shode now rises is 400 feet, and its level at Plaxtol is about 150 feet, the high ground on the summit of the banks of the valley at Shingle Hill being 550 feet higher: consequently, allowing the full thickness, 127 feet, for the Hythe Beds and Atherfield Clay, the stream ought to flow for the most part in the Weald Clay, and by the time it reaches Plaxtol it ought to have high clay-banks, exposing 423 feet of Wealden Beds. Such, however, is by no means the case. Fig. 2 (p. 174) shows a section from Shingle Hill, through Plaxtol to Hurst Wood, between figs. 3 and 4 of Prof. Prestwich.[1] Here the stream is seen, at 150 feet O.D., to have only just entered the Weald Clay, and one also notices that the high towering sides of its valley are composed almost entirely of 'Kentish Rag,' which extends to an altitude of 700 feet, although the deposit is only 100 feet thick. Moreover the Mote stream is seen to cut quite through the Hythe Beds at an altitude of nearly 400 feet, thus showing that the valley, instead of being one of simple erosion, is for the most part one of depression.

If we take a section along the Shode Valley (see fig. 3, p. 175) we find that such a depression really has taken place, approximately, from Plaxtol in a N.N.W. direction to below St. Clare. To this depression the yielding Gault Clay lent itself by forward progression, at right angles to the depression, by which the outcrop of the Gault is nearly doubled in width, as shown in the Geological Survey map of the district (Sheet 6). The Folkestone Beds, when made up of loose sand, also lent themselves to the stretch, but when more compact they cracked; the limestones of the Hythe Beds, on the other hand, became very much fissured.

For the purposes of this paper it is not necessary to enter further into the earlier geological history of the valley; of this, with the anthropological succession in the district, I hope to treat fully on another occasion. The exact date at which the depression took place has little, if any, chronometric value in connexion with the contents of the fissure: whether it was in the early stage of the Holmesdale Valley, when the Rag had 250 feet of Gault and Folkestone Beds above it, or whether it was after the river had actually pierced the former beds, is uncertain. One time-recorder remains, and that is, the amount by which the river has lowered its channel since its débris-charged waters first gained egress into the fissures, till the time when they were no longer able to do so.

An examination of the existing features of the surrounding country indicates that the Shode when it first entered the Hythe

[1] *Op. supra cit.* p. 272.

Beds,—or very shortly afterwards,—was flowing from N. to S. as now. Having previously cut through the Folkestone Beds it gained access to the fissures, and began to deposit its sediment in them; and it continued to do so during the whole period that its waters could carry materials into an unfilled space. Since this work of filling commenced, the river has cut its bed through about 85 to 90 feet of solid 'rag' at this spot. But deepening doubtless went on long after flood-waters reached for the last time the altitude of 300 feet, which was about the limit at which the fissures stopped filling.

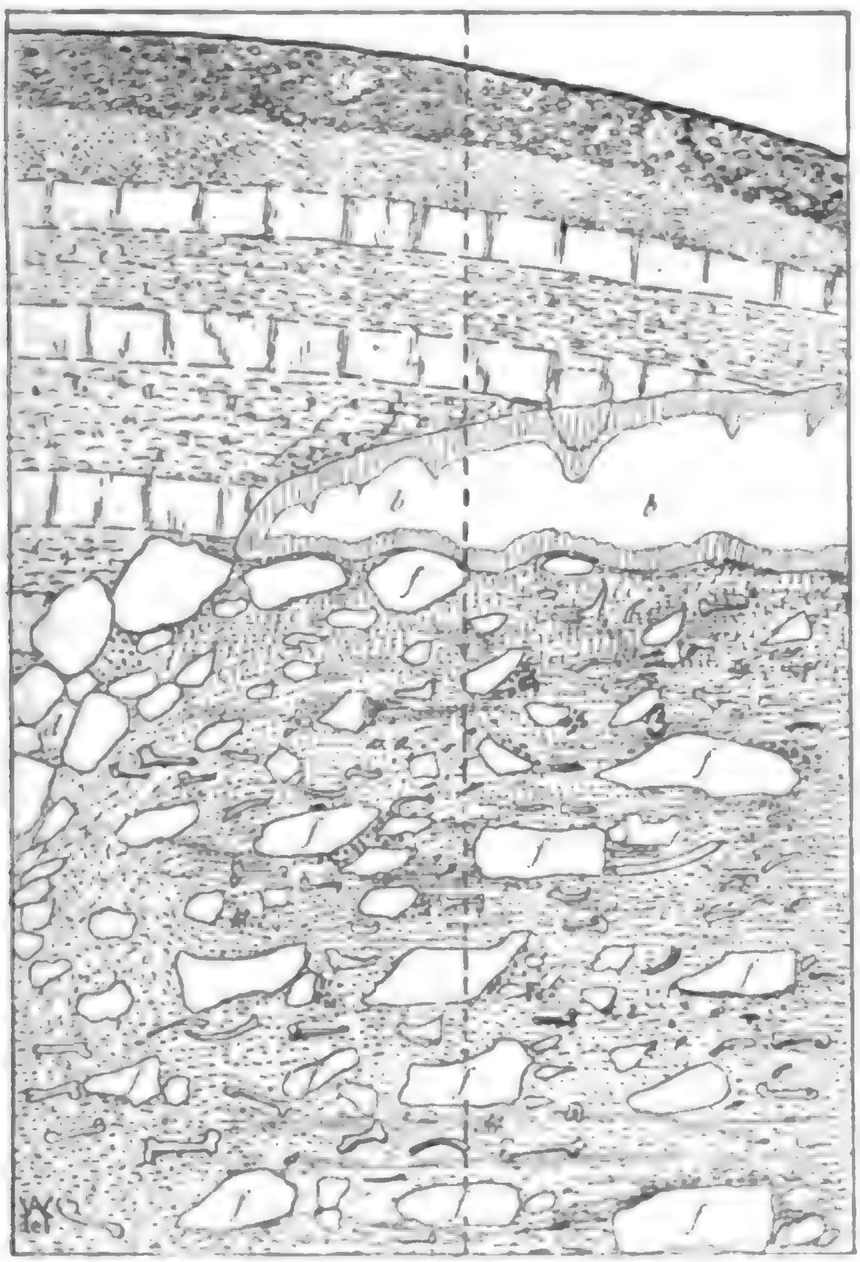
III. Description of the Fissures near Ightham.

Although there are numerous fissures in the Shode Valley, I shall confine myself to those on the western side of the promontory previously described. Here a quarry has been worked and a face 80 feet high exposed: the direction of the working is a little W. of N. by a little E. of S., thus revealing the fissures as seen in fig. 4, p. 178. The strike of these is practically at right angles to the direction of the downthrow of the valley. They are entirely in the Hythe Beds, which at this place consist of layers of exceptionally hard, slightly sandy, crystalline limestone—the Kentish Rag—alternating with friable, though often somewhat tough, beds of hassock; the thickness of the layers being from 1 to 2 feet for the rag, and 2½ to 3½ feet for the hassock. By the southward depression of the valley previously demonstrated, the beds are brought from a northerly dip to a horizontal position. There is a slight downthrow of about 18 inches to the south, the mass between *b* and *c* forming a miniature trough fault—a feature characteristic of the kind of earth-movement here undergone, the overlying hassock bending over and thickening in accommodating itself to the new conditions. A little farther down the valley the limestones are shown with a decided reversed dip.

The beds at the top have been very much altered, weathered, broken up, and decomposed for about 4 or 5 feet, and trailed down in the direction of the fall of the surface. It is still visible how the upper parts of fissures *a* and *d* have been bent and trailed down the hill; *d* towards the Shode, and *a* into the valley of the tributary. As these two fissures, and also *c*, had obviously been in contact with the surface, I confined my attention chiefly to *b*; of this fig. 5 (p. 179) is a generalized vertical section. The width of this fissure is from 1½ to 5 feet: when I first saw it, it did not reach the surface by about 4 feet; there was a ceiling of stalagmite about 12 inches thick; flocculent lime has also been redeposited into the cracks, crevices, and interstices of the grains of the adjacent rocks (shown in the figure by the wavy lines). Below the ceiling was an empty chamber (*b*) some 4 or 5 feet in height; the walls and floor were covered by a continuous deposit of lime, chiefly in the form of flos ferri at the sides; while white, with a slightly yellowish-brown tinge, granular stalagmite covered the bottom, some 3 or 4 inches

thick. Occasionally the stalagmites were crystalline. There was also a beautiful variety of arragonite, whiter and finer than the finest cotton-wool. The third inset, made by the quarrymen, that I saw, was about 80 yards from the present representative of the old stream, and showed the height of the fissure to be rapidly diminishing, and the top bending down in an arch, so that the two sides met the top in an angle, and the arragonite chamber formed a *cul-de-sac*. The deposition of flocculent lime extended 5 or 6 feet

Fig. 5.—*Generalized vertical section along fissure* b.



[The dotted line shows the present face of the quarry.]

into the underlying fissure-material, from which it appeared that the meteoric waters, which entered the chamber above, acted upon the fissure-earth, dissolved out the lime from both rock and bones, and redeposited it: the occurrence of bones increasing as the secondary deposition decreased. Owing to the decrease in the height of the fissure, this deposit quite sealed down all that was below it. Below this, towards the back, the fissure-material *d* (fig. 5) was more

friable and loose, presenting a washed-out appearance, probably due to the inability of the water-power to carry thus far anything but the lighter materials. The chamber-floor was about 300 feet O.D., and from this to the bottom of the working (which was only a very few feet from the present water-line or clay) it was full of a deposit (*c*, fig. 5) which might be described as an ordinary brick-earth, similar to that exposed in the valley, with the addition of lime and other materials of the mother-rock, not only of the friable hassock, but of blocks of rag varying in weight from a few ounces to nearly half a ton. These blocks (*f*) occur at all levels throughout the deposit, large ones frequently being tightly wedged in, and impossible to move without blasting. There are frequent boulders of Oldbury stone and chert, and occasionally a flint, the latter sometimes in the form of flakes; but up to the present no implements have been discovered in the fissure. The field (*g*) above was probably an encampment in Neolithic times, as neoliths occur in large numbers on the surface. One of the higher gravels was deposited upon the Folkestone Beds above the fissure; remains of the former still exist on the higher part of the field. There is also a patch of bleached white flint-gravel about 100 yards square, which I have just been able to trace home. These gravels were worked by Neolithic man, as often were similar deposits, but I have found no trace of man in the fissure—except a stray flint or two—and not a single neolith! The latter fact is very important in deciding whether the fissure has been reopened in more recent times than the period generally associated with *Rhinoceros*, *Elephas*, *Hyæna*, etc., or even whether it ever did open upon the surface. It is certain that in the early history of the filling of the fissure gravel covered the ground above it, but I have been unable to find any trace of it, even when the fissure was excavated to the lowest depths penetrated, which could only have been a very few feet from the underlying Atherfield Clay. On the other hand, the upper part of fissure *d* is full of a breccia similar to that seen on the surface at *g*.

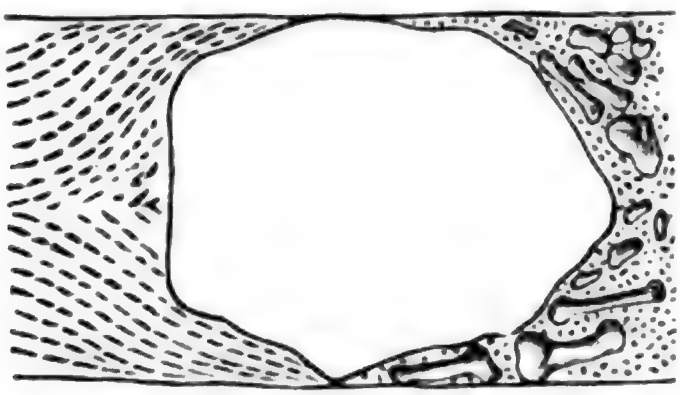
In places horizontal stratification was very distinct, fine layers of clay alternating with more sandy ones; but whether this was due to original stratification, or to the subsequent circulation of underground waters I should not like to say; a fissure a little lower down the valley still gives out water. In many places there were evidences of the levels at which the water stood at a particular time, by the adhesion in great profusion of calcified stems of *Chara* in a horizontal line upon the sides of the walls. The delicate scales of the slow-worm (*Anguis fragilis*) were also found adhering to the sides of the fissure for a distance of 20 feet, quite horizontally.[1] Very frequently on the stream side of a big block there would be an accumulation of the large bones, and in a similar position a few years ago a considerable number were found. On the inner side of such obstructions, unless either above or below them, it was useless to look for anything but the very smallest organic remains. As the

[1] These were about 60 feet above the present water-level.

quarry was worked in platforms from the top to the bottom downwards, I had a good opportunity of noting these features, which unmistakably pointed to the introduction of the débris-charged waters from the side and not from above. Those cases to which I particularly refer were about 30 feet from the top.

Fig. 6 shows a view from above of one of these 'keyed blocks.'

Fig. 6.—*Plan of one of the keyed blocks, seen from above.*



In this will be seen not only the stoppage of the large bones, but the direction of the waters as they deposited their sediment. It will also be obvious that, since the deposition of the fissure-material around these blocks, the position of the latter in regard to the former has not been changed. To my mind the wedged-in state of these blocks is very significant, for had they fallen from above during the filling of the fissure the deposit would have formed a bed for them, and so obviated the keying action; and seeing that after they fell they were covered with fissure-deposit, if the opening action had been continued after a stone had become keyed, we should not find a single stone so nipped to-day; whereas there are numbers in that condition all through the fissure, thereby showing that the process of opening was not a continuous one, and that the fissures have been stationary since their first filling.

IV. The Fossil Plants and Invertebrata found in the Fissure.

In working down the face of the quarry for the first time I kept all the fossils from the various levels separate, expecting to find a Cave-like succession; but on comparing them with my notes taken while work was progressing I could see nothing to warrant a separation either in the state of preservation of the specimens or in the occurrence of species—a conclusion simultaneously and independently arrived at by Mr. E. T. Newton. In some places certain species were naturally more plentiful than others; sometimes frog-bones were more numerous than all the rest of the bones put together, at others they were in the minority. I have seen a large wall of the deposit cleared on one side for a considerable distance, and throughout its whole extent it was perfectly solid; it is certain that water could not have transferred the fossils from one part of

the deposit to another or re-arranged its constituents. Occasionally, under large stones or in peculiarly situated spaces, the material was more friable and loose, or even a space left; but, so far as I could see from careful observations during nearly three years (in which time I handled, sifted, or washed scores of tons of material), I could see no possibilities of communication from one part of the fissure to another *to any great extent*. At the last inset, and as I worked the fissure farther back, the deposit was far less solid, more carbonaceous, and showed more cavities, and I quite expect this phase to increase as one works inwards.

It is the vertebrates, of course, that are the most important fossils of the fissure; but having stated the conditions under which they were found, I leave their description to far more competent hands than mine. I might, perhaps, remark that many of the bones are peat-stained, as though they had lain upon a peaty river-bank before entering the fissure, which colouring they never lost: they occurred irregularly all through the fissure in juxtaposition to the unstained bones. The same remarks apply to the gnawed bones. In a few instances, in the case of a bat, a vole, a mole, and a slow-worm, the creature entered the fissure very nearly or quite whole, and their bones occurred near each other; but it was usually otherwise, the bones being single and isolated.

List of Fossils other than Vertebrates.

Plantæ.

Corylus avellana (nuts).
Quercus robur (acorns).
Hypnum prælongum.
Chara.

Insecta.

Iulus.
Cynips, sp.
Otiorhynchus, sp.
Chrysomela, sp.
Porcella scaber.

Ostracoda.

Candona candida, Müll.

Mollusca.

Limax maximus, Linn.
Hyalina cellaria, Müll.
,, *alliaria*, Miller.
,, *crystallina*, Müll.
,, *fulva*, Müll.
Helix (*Patula*) *rotundata*, Müll.
,, *hispida*, Linn. (including Jeffreys' *concinna*).
,, *nemoralis*, Linn.
,, *ericetorum*, Müll.

Pupa muscorum, Linn.
Vertigo minutissima, Hartm.

Succinea oblonga, Drap.
Cyclostoma elegans, Müll. (top).
Unio, sp.? (minute fragments).

Helix (*Vallonia*) *pulchella*, Müll.
Cæcilioides acicula, Müll.
Cochlicopa (*Zua*) *lubrica*, Müll.
Carychium minimum, Müll.

REMARKS ON THE PLANTS AND INVERTEBRATES.

[*Plants*.—The stems of the *Chara* were in a state of calcic casts, and at first were very puzzling, and thought to be small annelid-tubes; but when submitted to W. Carruthers, Esq., F.R.S., he at once recognized their vegetable nature, and referred me to a collection of specimens in the Natural History Museum of the same description. Upon submitting them to Mr. R. B. Newton, F.G.S., he immediately identified them as similar to a large mass of *Chara* from Northampton described in the Geological Magazine for 1868, p. 563. On comparison of the specimens from the fissure with these, their identity became at once established. In the latter both nucules and globules are very plentiful in the entangled mass, but in those from the fissure I have only once or twice recognized the spiral structure of a nucule. Upon dissolving some of the stems under the microscope Mr. E. M. Holmes, F.L.S., revealed sufficient structure to assign them to *Chara* and not to *Nitella*.

Throughout the whole of the deposit nuts in a good state of preservation occurred. In the case of the acorns, the inside was a black, spongy, carbonaceous cast, but the outside skins were fairly well preserved. There are other vegetable remains which have not yet been identified.

At the back of the fissure exposed since the reading of the present paper there is far more carbonaceous matter, and I hope to be able to obtain more plants from it.

Insects.—Recently I have obtained upwards of a hundred tiny little globular bodies from ·75 to 1 millim. in diameter, usually single, but occasionally in clusters of three and four, which Mr. C. O. Waterhouse, F.Z.S., has identified as the galls of *Cynips*. To the same gentleman I am also indebted for identifying the insects. To Prof. T. Rupert Jones, F.R.S., I am indebted for naming the Ostracod.

Mollusca.—Of these the most plentiful species is *Hyalina cellaria*, which occurs all through the deposit; I obtained considerably over half a pint of specimens. The next in numbers is *Hyalina alliaria*; the whole of these are of a beautiful translucent pearly white, similar to those in the Portland fissures; there is not the slightest trace of animal matter or coloration in them. The Helicidæ come next, *Helix* (*Patula*) *rotundata* topping the list, in which species, as is usually the case in Pleistocene specimens, the colouring is still visible. The same remarks apply to *H. nemoralis* and *H. ericetorum*. The latter species was represented by only two or three specimens. *Succinea oblongata* was fairly common, and reached a length of 17 millim. The *Cyclostoma* was represented by an apical fragment of a spire. I also obtained several dozen molluscan eggs of various shapes and sizes, from 3 to 5 millim. in their major diameter; about half were pierced, but the rest were not, and when broken open showed no trace of any colouring. These have not yet been determined.

Vertigo minutissima calls for special notice, owing to its unusual

size, reaching a length of 6 millim. This species, I believe, had not been discovered in Pleistocene deposits until I obtained it from the New Admiralty section,[1] associated with *Betula nana*; in this deposit also the species attained a similar size, from which it would appear that the species has greatly dwindled in size since Pleistocene times. I also found on several occasions small fragments of a pearly, flaky shell which I have no doubt is *Unio*. The *Limaces* were represented by six specimens.

I handed the whole of the shells to Mr. B. B. Woodward, F.G.S., with whom I have had the honour of working for many years, without telling him whence they came, and asked him to kindly name and report upon them. In reply he said:—"Judging by its frequent occurrence in late Tertiary deposits, *Succinea oblonga* was far more common formerly than it is to-day. Its presence seems to indicate the proximity of very marshy ground. The *V. minutissimæ* are perfect giants! All the species are living at the present day, and the state of preservation is not such as to suggest any great antiquity."

The best estimate of their age can probably be made from their comparison with the fauna of a remarkable land-wash which exists in the neighbourhood. From this latter I obtained some 24 species belonging to 10 genera, and from the bottom of the deposit Neolithic flint-flakes, and pottery; but there are no signs of *Succinea oblonga*, nor is the general facies that of so water-loving an assemblage as that of the fissure. Still, with the exceptions of the fragments of *Unio* in the latter, no truly *aquatic* forms occur, although all of them are found in river-deposits elsewhere. In contrasting this land-wash, which is some 12 feet thick, with the fissure-deposit, I might observe that it contains scarcely a single bone, thus adding further, in my opinion, to the improbability of the fissure-deposit being a land-wash; while the absence of *album græcum* and path-trodden surfaces, the occurrence of single whole bones, unaccompanied either by fragments or foreign matter, is prejudicial to the idea of the bones having been carried in by, or as having made a passage through, carnivorous beasts or birds.—February 6th, 1894.][2]

[1] Proc. Geol. Assoc. vol. xii. (1892) pp. 346–356.

[2] [The last four species (see list on p. 182) have been added to the mollusca since the reading of the paper. Of these, *Helix pulchella* and *Cæcilioides acicula* are represented by a single specimen; of *Cochlicopa lubrica* there is also a single example, which is immature; none of these presents any features of special interest. The two specimens of *Carychium minimum*, on the other hand, call for some remarks, as they differ greatly from the type, and would no doubt be regarded by many as a new species, or at least a new variety. Seeing, however, that this species varies greatly, both Mr. B. B. Woodward and myself consider it inadvisable to found either a new species or variety on the material to hand. We have compared it with several hundred Pleistocene and recent examples, and find the following features and differences:—In outline it is altogether more slender than the type; it is fully 2·6 mm. in height, its width not exceeding ·75 mm. The whorls are six in number, more closely coiled, and consequently longer, and increase more gradually all through, so that the spire is higher and more tapering. The body-whorl is much less in proportion. The mouth is more rounded, and not at all constricted at the outer tooth; on the other hand,

V. Conclusions.

It is a little difficult to sum up the questions raised by the Ightham fissures and their contents until one has read Mr. Newton's paper. Still I think there are certain points which must be settled before a correct estimate can be made of the palæontological significance of these discoveries. They appear to me to be these:—

1. Was the filling up of the fissures effected by (*a*) a marine submergence, or even (*b*) were the contents washed in from a land-surface above? or

2. Were the fissures filled by the action of a river from the side?

3. Was the opening of the fissures a continuous and recurring one, after the first introduction of fissure-material, and the heretofore recognized Pleistocene mammalia; thus making the contents of the fissure belong to *any* age since the first opening? or

4. Did the river, when it first entered the fissures, find them of practically the same width as now? Was the filling confined to one period, and therefore the fossils all of one geological age?

The answers that suggest themselves to me are the following:—

1. (*a*) The fact that we have raised beaches extending a long way inland, left as relics of submergence, suggests that, had such an action taken place in the Ightham neighbourhood, with its land-locked depressions, some vestiges of it at least would have been left; and of all things in the world no traps would have been more fitted for the purpose than empty fissures. Yet I must admit that I have been unable to find a single particle of an obviously marine deposit. On the other hand, the whole of the contents are of terrestrial origin; and this, with the detached and gnawed condition of the bones, is to my mind hopelessly fatal to the hypothesis of a marine submergence.

(*b*) The description given in the Introduction (p. 171) of the absence on land-surfaces many miles in extent of the relics found in the fissures, and the extremely limited area of the little promontory in which the latter occur, dipping on all sides and covered with materials not found in the fissure, render it impossible for the filling to have been effected simply from above. We may be sure that, whatever might have been the agencies by which the Holmesdale Valley was scooped out, the soft Gault Clay would have given way before the harder Folkestone Beds (as is evinced by the lie of the older gravels), so that a northward extension of a gathering land-surface was truncated. The stream, however, extended over the Gault, and from this source derived the clay which forms a constituent of the fissure-material, both disseminated and as water-rolled

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the tooth itself is almost wanting, and is represented by a mere thickening of the labrum. The columella-teeth are not more than one-third the size of those in the recent species, and occur down inside the whorl so as to be invisible when the shell is viewed obliquely. The peristome is more reflected and less thickened, and consequently less 'toothy,' altogether presenting more the outline of *Paludestrina marginata*.—March 20th, 1894.]

pebbles, none of which exists in the sandy beds above the fissure; and from the Gault Clay pools were derived in times of flood the large quantity of *Chara*-stems. It thus appears impossible for the filling in to have resulted from marine submergence, or for the material to have been introduced in the form of a land-wash from above.

2. That the deposit was introduced into the fissures by a river is to my mind evident, from the fact that the material itself is exactly similar to that deposited in other sequestered spots in the valley, and the additional fossils constitute just such a heterogeneous mass as is to be found in the burdens of a river when preserved, and *nowhere else*. That water was present during deposition appears evident from the horizontal stratification of the sand and clay, and the scales of slow-worm and *Chara*-stems adhering in a straight line along the walls of the fissure; while the manner in which the fissure-material was forced upwards into blind veins and crevices from below is explicable on no other than an aqueous hypothesis. That the river was entering at the sides of the valley during a long period in the history of the filling of the fissure is absolutely certain from the damming action of the keyed stones, and the deposition of the material in passing round such large blocks.[1]

Coming to the mollusca, *Helices*, *Pupæ*, and the others are always found in river-deposits, and such forms as *Succinea* are never found far from water, but usually in it, while *Unio is never found elsewhere*. The preponderance of frog-bones over everything else, the large number of water- and bank-voles, the presence of *Chara* in such profusion, entomostraca, and *Triton* unmistakably point, in my opinion, to the fissure-deposit having had a river origin.

3 and 4. In the keyed stones, as it appears to me, we have an absolute answer to the question of the reopening of the fissures. We have seen that the keyed stones occur all through the deposit, into which position they were let fall, by the fissuring of the strata (or some may have been dislodged from the mother-rock by the entering of the water during the process of filling). It was in this keyed condition that they were when the deposit successively reached them. As the fissure filled the material became packed closely all round and over them, the inward transport of larger burdens being intercepted by these obstacles; and just as the material was originally deposited, so we find it to-day. Had a subsequent widening set in every stone originally keyed would have been loosened from the grip, and a keyed stone would have been practically an impossibility. It might, however, be urged that, by an unprecedented series of coincidences, every stone was so placed that when its hold was broken it ploughed through the solid material until it again became keyed, or fresh ones got into that condition. But if this were the case, and the stones moved out of their original position, all former

[1] Very careful and protracted observations lead me to consider that the downthrow of the valley did not occur till just immediately after the river had entered the Hythe Beds.

relations of stratification and filtration would have been obliterated; this, however, we know was not the case.

Attention might also be called to the fact that the bank on the top of the fissures became an old Neolithic settlement, neoliths being scattered over the surface literally in hundreds, yet not one of these was found in the fissure.

It is true that the mollusca might have borne a more aquatic facies, and not much can be said from a solitary entomostracon, but I have worked for many months at a river-deposit in which there were myriads of these little creatures, and only found one gasteropod, nor do any of the more aquatic forms occur in any deposit which I have worked in the valley outside.

We have, however, I think, far more evidence both positive and negative than we could reasonably have expected under the circumstances, that the fissures have never been reopened since they were first closed by the materials introduced into them by the river; and although it is within the bounds of possibility that in some unknown and incomprehensible manner some stray modern relic has been introduced, and in each case by some remarkable modification of chemical laws has been changed into a condition indistinguishable from those upon which the same forces have been operating for countless ages, there is still the great balance of probabilities that the whole of the contained fossils belong to one and the same geological period.

I am fully aware that there are many remains found here which have not been found before in recognized Pleistocene deposits; but that has been my experience with other sections at which I have worked for a long time. The increase in species is only such as to support the suggestions made by Mr. Clement Reid in connexion with the Forest Bed fauna,[1] namely, that late discoveries tend to show that it is the larger Pleistocene mammalia that have become extinct, and that the more we discover of the smaller creatures of this age, the more they approximate to those of our own time.

Even if we were to exclude from the lists all the species not previously found fossil elsewhere, we still have an extensive assemblage of the older Pleistocene forms which must have lived during the filling of the fissure: this therefore limits the filling operation to Pleistocene times.

In conclusion I have to express my hearty thanks to the officers of the Geological Survey, especially Messrs. Clement Reid, H. B. Woodward, and W. Topley, for the very great assistance which I have received from their invaluable advice, while it is unnecessary to remark that the chief value of the paper hinges upon the work bestowed by Mr. E. T. Newton upon the vertebrates. I have also to thank Mr. B. B. Woodward for his kind assistance in the determination of the mollusca, and Mr. C. O. Waterhouse for naming the insects.

[For the Discussion on this paper, see p. 210.]

[1] Mem. Geol. Surv. 1890, 'The Pliocene Deposits of Britain,' p. 182.

15. *The* Vertebrate Fauna *collected by* Mr. Lewis Abbott *from the* Fissure *near* Ightham, Kent. By E. T. Newton, Esq., F.R.S., F.G.S. (Read January 24th, 1894.)

[Plates X.-XII.]

Contents.

I. Introduction.

The remains of vertebrate animals collected during the last two or three years, with much care and in large numbers, by Mr. Lewis Abbott, from one of the fissures in the Kentish Rag near Ightham, in Kent, have been from time to time brought to me for examination and identification. The outcome of this study of many hundreds of specimens is contained in the present paper.

The occurrence of Pleistocene mammalian remains in Kent is well known, and Mr. W. Topley[1] has noticed such remains in the brick-earth filling long chasms in the Kentish Rag, which he alludes to as 'Pipes,' varying much in size and very numerous in the neighbourhood of Maidstone. In one such chasm at Boughton, 3 miles south of Maidstone, numerous bones were found by Mr. Braddick many years ago, and Dr. Buckland[2] was of opinion that these ossiferous cavities were 'caverns.' So far as I have been able to ascertain, this is the only recorded instance of mammalian remains being found in what appear to be caves or fissures in the Wealden area. The species found at Boughton are enumerated by Prof. Boyd Dawkins[3] in his paper on the 'Distribution of the British Post-Glacial Mammals,' namely, *Hyæna spelæa* [= *H. crocuta*], *Cervus tarandus*, *C. elaphus*, *Bos primigenius*, *Equus caballus*, *Rhinoceros tichorhinus*, and *Elephas primigenius*; all these species, with the exception of *Bos primigenius*, have been found in the Ightham fissure. The larger fossil mammalia of the South-east of England have received much attention at the hands of many investigators, and several valuable collections have been made, chiefly from the Thames Valley, notably that of Sir Antonio Brady, now in the British Museum, that of Dr. Cotton, preserved in the Museum of Practical Geology, and that brought together by Dr. Spurrell, of

[1] 'Geology of the Weald,' Mem. Geol. Surv. 1875, p. 179.
[2] Phil. Mag. ser. 2. vol. ii. (1827) p. 73.
[3] Quart. Journ. Geol. Soc. vol. xxv. (1869) p. 192.

Belvedere, and more recently by his son, Mr. F. C. J. Spurrell, which has lately been presented to the National Collections by the last-named gentleman. Although so much has been achieved for the larger Pleistocene mammalia, little or nothing was done, until the last few years, in the way of collecting the smaller vertebrates of these deposits. The admirable results obtained in this direction by Dr. Blackmore [1] and Mr. W. A. Sanford [2] in the West of England, and by Mr. Clement Reid [3] in the Norfolk Forest Bed, by means of careful washing, led me to suggest to several friends the desirability of collecting in the same manner the small vertebrates of the South-east of England. Something has already been done by Mr. R. W. Cheadle and by Mr. F. C. J. Spurrell [4]; and the magnificent series now exhibited is, with very few exceptions, the result of enthusiastic collecting by Mr. Lewis Abbott, who was the first to recognize the importance of the remains from this fissure, although a few specimens had previously been obtained by Mr. B. Harrison, of Ightham, whose collection of rude implements from the higher-level gravels of that neighbourhood is well known. The small bones from this fissure, when first found, were very friable, but are now, after Mr. Abbott's careful preparation with gelatine, in an admirable state of preservation; they represent mammals, birds, reptiles, and amphibians; but no fishes have been met with, although their remains have been diligently sought for.

I am under obligation to the officers of the British Museum and of the Royal College of Surgeons for the facilities afforded to me when working at the osteological collections under their charge. The Hunterian Museum series in the latter institution was found especially advantageous for the comparison of this large and varied series of fossils.

The remains of each species will now be passed in review, and, finally, some remarks will be made on the conditions under which they have been accumulated, and their relation to the Pleistocene faunas of other localities.

II. Review of the Species.

Amphibia.

Rana temporaria. (Common Frog.) Pl. X. figs. 1–3.—The remains of frogs in this fissure are far more numerous than those of any other animal. Nearly the whole of them are referable to the common species *R. temporaria*, and they include, together with nearly all other parts of the skeleton, the characteristic male humerus with its strong, backwardly directed ridges, the biconcave penultimate vertebra and procœlous sacrum, the comparatively

[1] See 'Flint Chips,' by Edw. T. Stevens, 8vo, London, 1870; also Blackmore and Alston, Proc. Zool. Soc. 1874, p. 460.

[2] Quart. Journ. Geol. Soc. vol. xxvi. (1870) p. 124.

[3] Mem. Geol. Surv., Vertebrata of the Forest Bed Series (1882).

[4] Geol. Mag. 1890, p. 452.

narrow ilium with its elongated tubercle above and well in front of the acetabulum, and parts of upper jaws with teeth. *Rana temporaria* has been found in the Forest Bed; it is now living in Northern and temperate Asia, as well as in Europe and Great Britain; in mountainous regions it occurs up to a height of 10,000 feet.[1]

Bufo vulgaris. (Toad.) Pl. X. fig. 4.—Among the many batrachian ilia, most of which have been referred to *Rana temporaria*, I have found five or six which, besides being more slender even than in the common frog, have a rounded tubercle just above the acetabulum; and, as these are among the characters which distinguish the skeleton of the toad from that of the frog, I have included these six ilia in the above species. *Bufo vulgaris* has been found in the Forest Bed; it is now living in Europe, Asia, and North-west Africa, as well as in Great Britain; its vertical range extends to 7000 feet.

Molga, sp. (=*Triton*). (Newt.)—Five small vertebræ and part of a skull, I have no doubt, belong to this genus, but the species is uncertain.

Reptilia.

Anguis fragilis. (Slow-worm.) Pl. X. figs. 5–7.—The remarkable ornamented and widely-bordered bony scales, by which this limbless lizard is completely encased, have been found in some numbers, together with vertebræ, parts of skulls, and lower jaws. There can be no doubt as to the identification of this form. *Anguis fragilis* is living throughout Europe, including Britain, but excepting the most northerly parts of Russia and Sweden; it has been met with as high as 7000 feet, and occurs also in Western Asia and Algeria.

Tropidonotus natrix. (Common Snake.)—About a dozen vertebræ, which agree with those of the common snake, are referred to this species, which has been recorded from the Forest Bed. It is now living in most parts of Europe, including Great Britain, from latitudes of about 58°, southward to Italy, as well as in Western and Central Asia and Algeria. It is known to range upwards to 5000 feet.

Vipera (Pelias) berus. (Viper.) Pl. X. figs. 8, 9.—The hinder two-thirds of a mandibular ramus is referred to this species; it agrees with the corresponding part of the viper in being anteriorly slender and rounded, deep in the coronoid region, and strongly curved from end to end. The common snake has the ramus of the lower jaw less curved, stouter throughout, and not specially deep in the coronoid region. Although the evidence is slight, there can be no doubt as to the correctness of this reference. The viper is now living throughout Europe from Northern Russia to the South of Spain and Italy, including Great Britain, but not Ireland; in mountain-ranges it is said to ascend to 9000 feet.

[1] I am indebted to Mr. G. A. Boulenger, of the British Museum, for the information regarding the vertical range of the amphibia and reptiles.

Aves.

The remains of Birds in this fissure are comparatively rare, and, although some eight different forms have been recognized, only one or two of them can be said to have been satisfactorily determined; they have been carefully compared with a number of recent skeletons, and the names given below are believed to be correct, but the small passerine birds are, in many cases, so much alike in their osteology, that it is difficult to distinguish their bones, and the want of skeletons for comparison prevents some of the other remains from being definitely named. All the forms of birds alluded to in this paper have a wide distribution, being found throughout the greater part of Europe and Asia, extending northward to or beyond the Arctic Circle, and southward to Northern Africa.

Turdus musicus? (Song-Thrush.)—The proximal half of a humerus, somewhat stouter than that of a lark and agreeing with that of a song-thrush, is all that can be referred to this species.

Saxicola Œnanthe? (Wheatear.) Pl. X. figs. 13, 14.—A humerus and two metacarpals are provisionally placed in this species.

Motacilla? (Wagtail.)—Two ulnæ seem to belong to either the pied or the white wagtail.

Anthus pratensis? (Meadow-Pipit or Titlark.)—A single coracoid seems to agree most nearly with this species.

Alauda arvensis. (Skylark.) Pl. X. figs. 10–12.—A humerus and three metacarpals are referred to this species. The same bones of the song-thrush are very similar in form and size to those of the skylark, but the humerus of the former is a trifle stouter, and the united metacarpals have a shorter opening left between them than they have in the latter. With these bones are associated a part of a tibia and two metatarsals. Two recent skeletons of this species which I have in my possession differ markedly in size, especially as regards their metatarsals; and the two fossil examples of this bone differ in a similar manner.

Buteo? (Buzzard?) Pl. X. fig. 18.—The greater part of a tarso-metatarsus of a large raptorial bird I am unable at present to identify with certainty. In general form it is like that of the common buzzard, though it is not only larger, but has the proximal part broader. Most probably it will prove to belong to the somewhat larger *Buteo lagopus*, but I have been unable to obtain a skeleton of that species for comparison.

Anas boscas? (Duck.) Pl. X. figs. 16, 17.—Two humeri agreeing very closely with the same bones of the common duck are provisionally placed in this species; and with them are associated for the present two ulnæ, which, being rather too large proportionately for the humeri, may represent another species. Three other fragments

are also included here. This species has been recorded from the Pleistocene of Fisherton, and possibly from other deposits of similar age, as well as from the Forest Bed.

Larus? (Gull.) Pl. X. fig. 15.—The distal half of a humerus closely resembling that of a gull or tern is provisionally placed in this genus; but at present I have seen no skeleton with which it exactly agrees.

MAMMALIA.

Insectivora.

Talpa europæa. (Mole.)—Remains of the common mole are plentiful in this fissure, and include bones from nearly every part of the skeleton. Although it may be questioned whether these remains are contemporaneous with the extinct forms, yet, as the mole occurs in the Forest Bed, there is no reason for doubting its occurrence in the Pleistocene. It is living throughout temperate Europe and Siberia; and, although found in Britain except in the northern parts of Scotland, is not met with in Ireland.

Sorex vulgaris. (Common Shrew.) Pl. XI. fig. 1.—Portions of several skulls and lower jaws, with teeth, as well as other parts of the skeleton, which agree precisely with the recent form, undoubtedly belong to this species, which has already been found fossil in the Forest Bed and in Caves. *Sorex vulgaris* is now living throughout Middle and Northern Europe, as well as in Britain, and extends in Russia to the 60° of north latitude. In the Alps it is met with up to heights of 6000 feet.

Sorex pygmæus. (Pigmy Shrew.) Pl. XI. fig. 2.—Three adult skulls and some perfect mandibular rami, with teeth similar to those of *S. vulgaris*, but much smaller, are referred to this species. *S. pygmæus* has been recorded from the Forest Bed. It is now living in Northern Asia and in Northern Africa, as well as in nearly every part of Europe, including Great Britain.

Cheiroptera.

Vespertilio Nattereri. (Reddish-grey Bat.) Pl. XI. fig. 3.—The remains of bats are very numerous, but the greater number of them are referable to this species. Parts of several skulls and many mandibular rami, some of which have all the teeth in place, present the characteristic dentition of the genus, namely $\frac{2}{3}, \frac{1}{1}, \frac{3}{3}, \frac{3}{3}$; they agree in size with this species, and the anterior cheek-teeth have similar proportions to each other, thus leaving little room for doubt as to the correctness of the determination. Femora, humeri, ulnæ, etc., of corresponding size are also associated with the skulls in this species. *V. Nattereri* is now living throughout Middle, and in some parts of Northern Europe, as well as in Britain.

Vespertilio ?—Several humeri, and a femur representing a bat intermediate in size between the pipistrella and long-eared bats, are provisionally placed in the genus *Vespertilio.*

Scotophilus pipistrellus ? (Pipistrella.)—Two small femora and two ulnæ, which agree in size with those of *S. pipistrellus*, are provisionally so named. This species is now living in Middle and Northern Asia as far eastward as Japan, also throughout Europe and Britain as far north as 60°.

Plecotus (Vespertilio) auritus ? (Long-eared Bat.)—A femur, several humeri, and ulnæ, which in size agree with those bones of *P. auritus*, as well as two lower-jaw rami, somewhat smaller than those of *Vespertilio Nattereri*, are provisionally referred to this species. It is now living in Europe (including Britain), from Spain and Italy northward to the 60th degree of north latitude in Scandinavia and Russia. In the Alps and the Harz it does not extend higher than the forest region.

Rodentia.

Lepus timidus. (Hare.) Pl. XI. figs. 4–5.—The bones referred to this species call to mind those from the Somerset Caves, recorded by Mr. W. A. Sanford,[1] which, on account of their larger size, were referred by him to *Lepus diluvianus.* It seems very doubtful, however, whether *L. diluvianus* is really a distinct species, and Dr. Woldřich[2] suggests that it may be only a variety of *L. variabilis.* The bones from the Ightham fissure, although larger and stouter than those of *L. timidus*, undoubtedly more nearly resemble the corresponding parts of that species than they do those of *L. variabilis.* The ilium of *L. timidus* is much broader proportionately than in *L. variabilis*; the Ightham specimen is likewise very broad. The femur of *L. timidus*, although absolutely shorter than that of the *L. variabilis* used for comparison, is stouter in every particular, and has the shaft flattened from above downward. The femur from the Ightham fissure, although as long as that of *L. variabilis*, has all the proportions of *L. timidus.* The humeri and other bones of these two species bear a similar relation to each other; and the corresponding fossil bones, which are referred to the present species, in each case similarly agree with *L. timidus*: these include tibiæ, humeri, ulnæ, radii, foot-bones, and a pair of lower incisors. Two pieces of ulnæ seem to have a nearer resemblance to *L. variabilis*, but they are not sufficient for identification. *Lepus timidus* has been recorded from Pleistocene deposits; it is now living from the north of Russia to the south of Spain and Italy, and occurs in the southern parts of Sweden; but, although common in England, is not found in Ireland, where it is replaced by *Lepus variabilis.* In Scotland both species are found.

[1] Quart. Journ. Geol. Soc. vol. xxvi. (1870) p. 126.
[2] Sitzungsb. d. k. Akad. d. Wissensch. Wien, vol. lxxxii. (1880) p. 11.

? *Lepus cuniculus.* (Rabbit.)—Several portions of tibiæ certainly belong to the common rabbit and to young individuals, but there is much doubt as to their being contemporaneous with the other remains with which they are now associated. The burrowing habits of the rabbit make it probable that these remains belong to a later period. The rabbit is a South European form, and although now abundant in many parts of Central Europe and in Britain, is probably not indigenous to any area north of the Alps.

Lagomys pusillus. (Pika or Tailless Hare.) Pl. XI. fig. 6.—The left ramus of a lower jaw, wanting the articular process and the anterior cheek-tooth, leaves no doubt as to the presence of *Lagomys* in this fissure. The recent species of the genus exhibit a remarkable similarity in the pattern of their teeth, and in absolute size there is less difference than might be expected from the variations in this respect observable in the skulls and skeletons of the different species. In size, however, as well as in the length of the entire row of five cheek-teeth (6·7 millim.), the fossil comes nearest to *Lagomys pusillus.* The complex anterior, or penultimate, premolar is wanting, but the alveolus shows that its grinding surface had a triangular form. The three intermediate grinders are alike, and each has an anterior and a posterior prism of dentine, surrounded by enamel, which are as nearly as possible of the same size; the last molar is very small, and consists of a single prism. The remains of *Lagomys*, found in British Caves, were referred by Owen to a new species, *L. spelæus*, but are now generally included in the species *L. pusillus*; and seeing that the jaw from the Ightham fissure agrees best with the same living form, there is no hesitation in referring it also to *L. pusillus.* This species is at the present day living in the southern districts of the Volga and Ural Mountains, as well as in Southern Siberia as far east as the River Obi.

Spermophilus.—Portions of six right mandibular rami, the upper parts of a cranium, parts of two humeri each with an epicondylar foramen, and parts of four ulnæ are referred to this genus. Unfortunately the parts preserved, including two cheek-teeth, are not sufficient for specific identification. All these remains seem to be rather smaller than those from Erith, which have been named *S. erythrogenoides*, but it is quite possible that they may belong to that species. *Spermophilus* is not now living in Britain.

Mus sylvaticus. (Long-tailed Field-Mouse.) Pl. XI. fig. 7.—About forty lower-jaw rami and portions of four skulls are referred to this species. Four of the rami have the anterior cheek-teeth in place, and these show the deep longitudinal groove, with an anterior and two outer accessory cusps similar to those of *Mus sylvaticus*, except that the more anterior of the outer accessory cusps is compressed and apparently more definitely separated from the paired cusps. But as there is some variation to be seen in this respect in the teeth of *Mus sylvaticus*, and sometimes there is even an additional accessory cusp, it would scarcely be justifiable to separate these fossils from

the common living species. The largest of these rami measures about 15·5 millim. from the point of the incisor tooth to the articular condyle; while the three cheek-teeth occupy about 3·6 millim. and the front tooth 1·7 millim.—measurements which agree with those of *M. sylvaticus*. One or two front upper cheek-teeth are preserved, which agree with this species. *Mus sylvaticus* has been found in the Forest Bed, is now living in nearly the whole of temperate Europe as well as in Britain, and is found in Western Siberia and the Caucasus. In the Alps it extends upward to 6000 feet above the sea.

Mus Abbotti, sp. nov. Pl. XI. fig. 8.—Seven mandibular rami and parts of four skulls, considerably larger than those referred to *M. sylvaticus*, it was at first thought might belong to one of the small species of *Cricetus*[1]; but fortunately one of the rami has all the teeth preserved, and a second has the front cheek-tooth in place; these teeth are found to agree with *Mus*, and not with *Cricetus*. All the cheek-teeth are well worn, and the pairs of cusps have united laterally, but the longitudinal groove is deep and similar to that in *M. sylvaticus*. The front cheek-tooth wants the anterior accessory cusp, or has it very small; in one example it has united with the anterior pair of cusps, while in another specimen it is so small as only to be seen with difficulty. The hinder and outer accessory cusp is as in *M. sylvaticus*, though the accessory cusp opposite the median pair is reduced to a compressed and elongated ridge, as in some of the specimens referred to *M. sylvaticus*, and like that which obtains in *M. minutus*. In *M. sylvaticus* this same cusp sometimes has a compressed appearance and is little more than a part of the outer cingulum. The second and third cheek-teeth in the present form are like those of *M. sylvaticus*. Four portions of skulls are provisionally associated with these lower jaws; they are without teeth, and are not only larger than in *M. sylvaticus*, but have proportionately wider palates, shorter noses, and broader interorbital spaces. The teeth of this mouse agree most nearly with those above referred to *Mus sylvaticus*, differing, however, from that species in the absence or slight development of the anterior accessory cusp of the front lower cheek-tooth. The length of the best-preserved ramus, from the point of the incisor to the articular condyle, is 18·8 millim.; the entire series of cheek-teeth measures 4·1 millim., and the anterior cheek-tooth 1·8 millim. The only fossil species that need be mentioned is the *Mus orthodon*, Hensel,[2] the teeth of which, so far as one may judge from the much-worn examples which are figured, approximate to the present fossil; but as the front cheek-tooth of that species is one third larger than that of the specimens now being considered, the two cannot well be referred to the same species. I propose to name this new form *Mus Abbotti*.

[1] See Nehring, 'Ueber Pleistocäne Hamster-Reste,' Jahrb. d. k.-k. geol. Reichsanstalt, vol. xliii. (1893) p. 179.

[2] Zeitschr. Deutsch. geol. Gesellsch. vol. viii. (1856) p. 281. See also Dr. Forsyth Major, Atti Soc. Toscana di Sci. Nat. Proc. Verb. vol. iv. (1884) p. 129.

Myodes lemmus. (Norwegian Lemming.) Pl. XI. fig. 9.—Two mandibular rami and a single cheek-tooth are all the remains which can be definitely referred to this species. The front cheek-tooth has 4 inner and 3 outer angles (or 5 and 4, if the very slight angles of the small anterior prism be counted), the prisms having the open lax arrangement distinctive of the Norwegian lemming. The jaws, when perfect, must have been about the same size as the largest of those referred below to *M. torquatus*. *Myodes lemmus* is known as a Pleistocene species; at the present day it is living in the Scandinavian peninsula and in Russian Lapland.

Myodes torquatus. (Arctic Lemming.) Pl. XI. fig. 10.—Twelve mandibular rami, of different sizes, more or less perfect, and for the most part with their teeth in place, represent this species. These rami are intermediate in size between *Microtus amphibius* and *M. agrestis*, and the front cheek-tooth has the 5 outer and 6 inner angles characteristic of the Arctic lemming. Among the rodent limb-bones alluded to below several distinct sizes may be distinguished, between those which agree best with *Microtus agrestis* and those referred to *M. amphibius*. The largest of them are much smaller than those of *M. amphibius*, and may belong to the present species or to *Myodes lemmus*; but on comparison with the skeletons of *M. torquatus* in the British Museum they are found to be stouter, and the femora and humeri have distinctly larger heads. *Myodes torquatus* occurs in Pleistocene deposits in England and on the Continent, but is at the present day a purely Arctic animal, living, according to Coues and Allen, in Arctic America, Greenland, and corresponding latitudes in the Old World.

Microtus (=*Arvicola*) *glareolus.* (Bank-Vole.)—To this species are referred more than a dozen lower-jaw rami, the front cheek-teeth of which have the characters of *M. glareolus* (4 outer and 5 inner points). Two of these rami belonged to aged animals, the teeth being strongly rooted. The smallest of the arvicoline limb-bones among these fossils are shorter and stouter than those belonging to recent examples of this species, and it is possible that some of those which come near to *M. arvalis* may belong here. *Microtus glareolus* has been found in the Forest Bed, in Caves, and in Pleistocene river-deposits; it is now living in Britain and throughout Europe; it extends southward to the Apennines, and northward to within the Arctic Circle.

Microtus (=*Arvicola*) *amphibius.* (Water-Vole.)—About twenty lower-jaw rami, very perfect, and several portions of skulls, as well as many incisor teeth, pelvic bones, femora, tibiæ, humeri, ulnæ, and radii, are without any doubt referred to this species—the front lower cheek-teeth having the characteristic pattern, namely, 5 inner and 4 outer angles. *Microtus amphibius* has been found in Pleistocene deposits, and possibly also in the Forest Bed; it is now living throughout Europe as well as in Great Britain, and extends eastward through Siberia.

Microtus (= *Arvicola*) *arvalis*. (European Field-Vole.)—Portions of nearly a dozen skulls, mostly rather smaller than those referred to *M. agrestis*, are placed in this species. Eight of them have the second cheek-tooth preserved, which shows, in each case, only 5 angles; while some have the hinder cheek-tooth present and showing 4 inner and 3 outer angles. Several lower-jaw rami are associated with these skulls; they are rather smaller than that referred to *M. agrestis*, but have the front cheek-tooth showing the angles characteristic of both these species, namely, 5 inner and 4 outer. There are many limb-bones which may belong to this species or *M. glareolus*, or perhaps to *M. agrestis*. *M. arvalis* has been found fossil in the Forest Bed and in a fissure-deposit near Frome. It is extinct in Britain, but is now living in Middle Europe from the Atlantic to the Urals, and also in Western Siberia in steppe regions. In the Alps it ascends to a height of 6000 feet.

Microtus (= *Arvicola*) *agrestis*. (Field-Vole.)—Portions of two skulls, with the characteristic upper second cheek-tooth (6 points) in place, undoubtedly represent this species; and with these are associated several lower-jaw rami, which are rather larger than those referred to the last species, but have the form of tooth (5 inner and 4 outer angles) characteristic of both *M. agrestis* and *M. arvalis*. The limb-bones, which on account of their length might be referred to this species, are not certainly determinable, the femora especially being stouter and having larger heads than in the recent specimen. *Microtus agrestis* has been recorded from English Caves; it is now living in Middle and Northern Europe, as well as in Britain, and ranges southward as far as the Alps and Pyrenees (where it extends to a height of 4000 feet), but is more plentiful in the north, reaching in Scandinavia to 66° of north latitude.

Microtus (= *Arvicola*) *ratticeps*. (Northern Vole.) Pl. XI. fig. 11.—Two lower-jaw rami and three of the characteristic teeth are all that I am able to refer to this species; but possibly some of the portions of skulls noticed under *M. gregalis* may belong here. The front cheek-teeth still remaining in the jaws, as well as the separate teeth, have each 5 inner and 3 outer angles, the anterior prism being confluent with the fourth inner prism. This and the three previously noticed species are so nearly of the same size that it is probable some of the smaller limb-bones already mentioned may belong to the present form. *M. ratticeps* has been found in Caves and other Pleistocene deposits. It is not now living in Britain, but occurs throughout Northern Europe, from Scandinavia to the Urals, and also over a large part of Siberia.

Microtus (= *Arvicola*) *gregalis*. (Siberian Vole.) Pl. XI. fig. 12.—Nearly forty small rami, varying somewhat in size, are referred to this species on account of the structure of the anterior cheek-tooth. This tooth has 5 inner and 3 outer angles, the anterior enlarged prism being continuous with the fifth, but shut off from the fourth inner prism. This form of tooth is much like that of

M. ratticeps, for which it may easily be mistaken; but in *M. ratticeps* the front prism of this cheek-tooth is continuous with the fourth inner prism, and is not shut off from it by the enamel fold, as it is in the present species. There are portions of four skulls which may belong to this species or to *M. ratticeps,* the posterior cheek-tooth having 4 inner and 4 outer angles. *Microtus gregalis* has been found in the Norfolk Forest Bed and in Pleistocene deposits on the Continent. It is now living in the treeless regions of Siberia, east of the River Obi.

Limb-bones of small Rodents.—In addition to the skulls and lower jaws of small rodents above noticed, numerous limb-bones have been met with; but, while the jaws with teeth can be referred to the genera and species given above, there is much difficulty in correlating the other bones with them. The limb-bones, especially the femora and humeri, may be separated according to their sizes and proportionate robustness into about a dozen groups. The largest of these bones agree satisfactorily with *Microtus amphibius*; but few, if any, of the others present a sufficiently close agreement with such recent forms as I have been able to compare them with, to render a reference certain. In many cases the fossil bones which seem most nearly to resemble any particular living species are found to be not only stouter, but to have proportionately larger heads. At present, therefore, many of the limb-bones have not been specifically determined.

Ungulata.

Elephas primigenius? (Mammoth.)—The only evidence of the Elephant in the Ightham fissure is supplied by one of the smaller bones of the tarsus, a well-preserved third cuneiform bone of the left side, and possibly by some pieces of large ribs. There is no doubt as to the foot-bone belonging to *Elephas*, and so little as to its being Mammoth that I have placed it in this species. There is some doubt as to whether the Mammoth occurs in the Forest Bed.

Equus caballus. (Horse.)—Portions of two scapulæ, a piece of femur showing the third trochanter, a first digital phalange, and a splint-bone of a good-sized horse are referred to this species, the Pleistocene form being now recognized as at most a variety of the recent *E. caballus*. An ungual and one other phalange of a much smaller horse have also been found. The domestic horse is almost certainly identical with the form found so abundantly in Caves and Pleistocene river-deposits, and extends back in time at least as far as the Forest Bed.

Rhinoceros antiquitatis. (Woolly Rhinoceros.) Pl. XI. figs. 13–15.—Four well-preserved milk-teeth of this species have been found; they are the first, third, and fourth deciduous molars of the left upper jaw, and the third deciduous molar of the right lower jaw. The upper teeth possess the completely separated median accessory valley

so characteristic of this species. The fourth tooth is only slightly worn. There can be little doubt that these teeth all belonged to one animal, and were most probably united by the jaw when first unearthed; they are in too perfect a condition to allow of the suggestion that they have been derived from an older deposit, all the edges being as sharp as when the animal was alive. The shaft of a large and gnawed humerus and part of a much denuded atlas vertebra most likely belong to this species. *Rhinoceros antiquitatis* is only known from Pleistocene and Cave deposits; but in these it has been found at many localities in England, Europe, and Siberia.

Cervus elaphus. (Red Deer.)—Part of a scapula agreeing in form with that of a red deer, but bigger than the specimen with which it has been compared, is referred to this species, which it is well known attained to a large size in Pleistocene times. This scapula is not so large as that of *C. giganteus*, and the spine does not approach so near the glenoid cavity; in size it agrees with that of a small ox, but is not of the same form. A piece of lower jaw with two milk-teeth in place is likewise referable to this species. The red deer occurs in the Forest Bed and in Caves and Pleistocene river-deposits; it is now living not only in Britain and the temperate regions of Europe, but also in a large part of Siberia.

Rangifer (=Cervus) tarandus. (Reindeer.) Pl. XI. fig. 16.—A portion of a right mandibular ramus, with two milk-teeth in place, agrees so precisely, as regards the size and pattern of the teeth, with the lower jaw of a reindeer of similar age in the British Museum, as to leave no doubt regarding their specific identity. The articular half of a scapula, showing tooth-marks of a small carnivor, gives additional definite evidence of the same species. On comparing the scapula of a reindeer with those of the red and fallow deer, it will be noticed that the reindeer differs from both the latter in having the spine descending nearer to the glenoid cavity, a smaller coracoid process, and the prescapula wider, so that it forms a more distinct ledge. The general effect of these differences is to give a less constricted appearance to the region a little above the glenoid cavity. Two pieces of femora, although a little smaller than those of the reindeer in the Museum of the Royal College of Surgeons, may perhaps belong to this species. The reindeer, which is very common in Caves and Pleistocene river-deposits, was still living in the North of Scotland at the beginning of the 12th century. It is now restricted to the far north in Europe, Asia, and America, its southern limit following very nearly the isothermal line of 32° Fahrenheit, and consequently it is found farther south in America than in the Old World.

Capreolus caprea. (Roedeer.)—A gnawed femur, two metatarsal bones, and possibly a toe-bone, are all the parts of this species yet found. The roedeer has been met with in the Forest Bed, also in Caves and Pleistocene river-deposits; it now occurs over all

Europe, except much of Russia, and is scarcer in the northern countries than it is in the south.

Sheep? Goat?—There are two tibiæ among these remains, which I am unable satisfactorily to determine; but as it is possible that they may belong to sheep or goat, it is perhaps best to mention them.

Sus scrofa. (Pig.)—The only specimen representing this species which has yet been found is a single first upper-molar tooth. The species is known in the Forest Bed, as well as in Caves and Pleistocene river-deposits; it is now living in Europe and in Asia, extending beyond the 55th degree of north latitude, and occurs in North Africa.

Carnivora.

Mustela robusta, sp. nov. Pl. XI. figs. 17, 18.—A left humerus, a right ulna, and some foot-bones from the Ightham fissure undoubtedly belong to the genus *Mustela*, but I cannot refer them to any known species. There can be no question as to their close relation to the marten and polecat, agreeing as they do in minute particulars with the corresponding bones of these animals; in length, however, they are intermediate between those two species, and are, at the same time, absolutely stouter in build than the much longer bones of the marten. The humeri of the marten and polecat used for comparison present certain slight differences, and in these particulars the fossil humerus agrees best with that of the polecat. The deltoid ridge in the marten is not so strongly developed, neither is the front of the humerus in this region so much flattened as it is in the polecat and in this fossil. In the last two forms also there is a fine raised line, accompanied by a narrow groove, extending from the inner side of the deltoid prominence downward to the inner side of the epicondylar foramen, which is not seen in the marten; and further, the marten's humerus is more suddenly contracted above the epicondylar foramen than in the other two forms. The strong supinator ridge and entepicondylar foramen are similar in all three humeri, but the ridge is proportionately strongest in the fossil, in which also the width of the distal end of the bone is absolutely greater than in the marten. The length of this fossil humerus is 54 mm., the width of the proximal end 12 mm., width of distal end 15 mm., the smallest circumference of shaft 16·5 mm.

The ulna, as already stated, is intermediate in length between that of the polecat and marten, but is absolutely stouter than in the marten, and the olecranon process is especially broad. The inner and distal end of this ulna has the prominent, elongated, and sharp ridge found in *Mustela*; while the opposite side of the bone near the middle has a well-marked prominence for the attachment of the ulno-radial ligament.

Two metacarpals and a metatarsal, which are intermediate in size between the same bones in the polecat and marten, while

having a similar form, are referred to this species, as well as a single upper canine tooth larger than that of the polecat. As it is desirable that this new form should have a name, I have called it *Mustela robusta.*

Mustela vulgaris, var. *minuta*. (Small Weasel.) Pl. XI. figs. 19, 20.—A small, right mandibular ramus, with most of the teeth in place, is certainly that of a *Mustela*, and although smaller than any specimen of *M. vulgaris* with which I have been able to compare it, would correspond with the smallest skull of this species measured by Hensel.[1] Two adult tibiæ, with epiphyses firmly ankylosed, and agreeing with those of the common weasel in every particular except size, are included with the lower jaw as a small variety of *Mustela vulgaris*, which is the smallest known carnivor. These tibiæ are each 18·5 millim. long, which is nearly one third shorter than that of an ordinary-sized weasel, and a little less than that figured by Woldřich[2] as *Fœtorius minutus*, or than would correspond with the mandibular ramus above mentioned. The weasel has been recorded from Caves; besides being a native of Britain, it is generally distributed throughout Europe, extending into Northern Russia and over a large part of Siberia.

Meles taxus? (Badger.)—Several bones of a very young animal, without epiphyses, are believed to be those of a badger, but I have been unable to compare them with a similarly young recent specimen, and the determination is therefore uncertain. This species has already been found in Caves and Pleistocene river-deposits in Britain; it now ranges over the whole of Europe, including Britain, from the Mediterranean northward, beyond 60° of north latitude.

Ursus arctos? (Brown Bear.) Pl. XII. fig. 10.—The metacarpal of a bear, which has the proximal articulation destroyed, is all that has been found of this genus. In size and form this bone agrees best with the fifth metacarpal, left side, of *Ursus arctos*, but the specific determination is not quite certain. The brown bear has been found in Pleistocene deposits, and, although extinct in Britain, is now living throughout Europe and Asia, extending even into North America. It ranges southward to the Pyrenees and northward nearly to 70° of north latitude.

Hyæna crocuta? (Spotted Hyæna.) Pl. XII. fig. 11.—Although several bones have been found evidently gnawed by *Hyæna*, especially a humerus of *Rhinoceros*, of which only the middle of the shaft remains, yet the sole direct evidence of the genus is a single much denuded canine tooth, which is not sufficient for specific identification. *Hyæna crocuta* has been found in the Forest Bed, Pleistocene river-deposits, and Caves; it is now confined to Africa, south of the Sahara.

Canis vulpes. (Common Fox.) Pl. XII. figs. 1–4.—The Ightham fissure has yielded numerous bones of foxes, representing nearly

[1] Nova Acta Acad. Leop.-Carol. vol. xlii. (1881) p. 125.
[2] Denkschr. d. k. Akad. d. Wissensch. Wien, vol. lx. (1893) p. 614.

all parts of the skeleton. These bones naturally fall into two sets; one agreeing in size with the common fox, and another in which all the bones are of a smaller size. The latter set evidently belong to a second species, *Canis lagopus*, and will be noticed below. The larger bones are the most numerous, and are unhesitatingly referred to *Canis vulpes*: the jaws and teeth, as well as the other bones of the skeleton, presenting no characters either of size or form different from those of *C. vulpes*. Some of the bones, as will be seen by the measurements, are larger than those of the female fox given for comparison, and doubtless belonged to a male, while some appear to have belonged to a smaller example. The common fox has been found in Caves and in Pleistocene river-deposits; it is now living throughout the greater part of Europe and Asia, ranging from Britain and Scandinavia to Kamtchatka, as far northward as trees flourish; it is also met with in Africa, north of the Sahara.

Measurements of Foxes' Bones (in millimetres).

	C. vulpes. ♀	*C. lagopus.* ♂	*C. lagopus.* ♀	*C. vulpes.* Ightham.	*C. lagopus.* Ightham.
Length of entire row of cheek-teeth of lower jaw	60	53	49	58 to 61	49 to 50·5
ditto ditto upper jaw	54·5	48	44	50	45
Length of lower carnassial ...	16·4	13·5	13	15 to 16·5	12·5 to 13·6
„ upper „ outside	14	12·5	12	13	12
„ femur	130	110	100	123 to 132	104
„ tibia..................	142	126	113	134 to 135	110 to 114
„ humerus	123	111	96	117 to 127	96
„ radius	118	103	92	108 to 119	91
„ ulna..................	139	122	108	143	106

Canis lagopus. (Arctic Fox.) Pl. XII. figs. 5–9.—The series of smaller canine bones, which are referred to this species, includes upper and lower jaws with the cheek-teeth, as well as representatives of each of the limb-bones and many of those of the feet. Only the complete bones have been used for the measurements given in the table, and it will be seen that one of them, the radius, is a trifle smaller than that of the female *C. lagopus*, while all the other measurements are intermediate between those of the same parts in the male and female *C. lagopus*.

Dr. Woldřich[1] has used the name of *Vulpes meridionalis* for certain fox-bones from the 'Diluvium' which are said to be smaller than *C. lagopus* and to have a proportionately narrower upper carnassial tooth. The upper carnassials, preserved in the jaws from Ightham, are slightly more compressed than in the *C. lagopus*, referred to by Dr. Woldřich, and closely resemble those of *V. meridionalis*, but

[1] Denkschr. d. k. Akad. d. Wissensch. Wien, vol. xxxix. (1878) p. 143; also Sitzungsb. d. k. Akad. d. Wissensch. Wien, vol. lxxxii. (1880) p. 38.

this, it seems to me, may be due to individual variation; and seeing that the other measurements fall so well within the limits of those of *C. lagopus*, I regard these Ightham remains as belonging to the Arctic fox. So far as I am aware, the only record of the Arctic fox in Britain was made by Busk in 1875,[1] when he described an axis vertebra from Cresswell Crags; but Dr. Blackmore, of Salisbury, tells me that in 1879 he obtained a skull of this species in the brick-earth of Fisherton. It is satisfactory, therefore, to be able to confirm these discoveries by the finding of a number of specimens in the Ightham fissure. *Canis lagopus* is now living in the Arctic regions of Europe, Asia, and America, and also in Spitzbergen and Iceland.

III. Table of Distribution of the Vertebrata found in the Ightham Fissure.

N = range north. S = range south. A = Arctic.

Names of Genera and Species.	Living in Britain.	Living out of Britain.	Extinct.	Pleistocene Deposits.	Caves.	Forest Bed.
Amphibia.						
Rana temporaria, Linn.	*	*	...	...	...	*
Bufo vulgaris, Laurent.	*	*	...	...	...	?
Molga (= *Triton*)	*	*	...	...	...	*
Reptilia.						
Anguis fragilis, Linn.	*	*				
Tropidonotus natrix, Linn.	*	*	...	...	...	*
Vipera (*Pelias*) *berus*, Linn.	*	*	...	...	...	*
Aves.						
Turdus musicus? Linn.	*	N.S.				
Saxicola Œnanthe? Linn.	*	N.S.				
Motacilla?	*	N.S.				
Anthus pratensis? Linn.	*	N.S.				
Alauda arvensis, Linn.	*	N.S.	...	...	*	
Buteo?	*	*				
Anas boscas? Linn.	*	N.S.	...	*	...	?
Larus?	*	*				

[1] Quart. Journ. Geol. Soc. vol. xxxi. p. 685.

TABLE (*continued*).

Names of Genera and Species.	Living in Britain.	Living out of Britain.	Extinct.	Pleistocene Deposits.	Caves.	Forest Bed.
MAMMALIA.						
Talpa europæa, Linn.	*	N.	...	...	*	*
Sorex vulgaris, Linn.	*	N 60°.	...	...	*	*
—— *pygmæus*, Pallas	*	N.S.	...	...	...	*
Vespertilio Nattereri, Kuhl	*	*				
——, sp.	?	?				
Scotophilus pipistrellus? Geoff.	*	N 60°. S.				
Plecotus auritus? Linn.	*	N 60°. S.				
Lepus timidus, Linn.	*	N.S.	...	*	*	
? —— *cuniculus*, Linn.	*	S.	...	...	?	
Lagomys pusillus, Pallas	...	*	...	...	*	
Spermophilus	...	N.	...	*	*	
Mus sylvaticus, Linn.	*	*	...	...	...	*
—— *Abbotti*, n. sp.	...	...	*			
Myodes lemmus, Linn.	...	N.	...	*	*	
—— *torquatus*, Desm.	...	A.	...	*	*	
Microtus (=*Arvicola*) *glareolus*, Schreib.	*	N.S.	...	...	*	*
—— (——) *amphibius*, Linn.	*	N.S.	...	*	*	?
—— (——) *arvalis*, Pallas	...	*	...	...	*	*
—— (——) *agrestis*, Linn.	*	N 66°. S.				
—— (——) *ratticeps*, K. & B.	...	N.	...	*	*	
—— (——) *gregalis*, Pallas	...	*	...	...	...	*
Elephas primigenius? Blum.	...	...	*	*	*	?
Equus caballus, Linn.	*	*	...	*	*	*
Rhinoceros antiquitatis, Blum.	...	...	*	*	*	
Cervus elaphus, Linn.	*	*	...	*	*	*
Rangifer (= *Cervus*) *tarandus*, Linn.	...	N.	...	*	*	
Capreolus caprea, Gray	*	S.	...	*	*	*
Sus scrofa, Linn.	*	*	...	*	*	*
Mustela robusta, n. sp.	...	...	*			
—— *vulgaris*, var. *minuta*	?	?				
Meles taxus? Bodd.	*	*	...	*	*	
Ursus arctos? Linn.	...	N 70°. S.	...	*	*	
Hyæna crocuta? Erxl.	...	S.	...	*	*	*
Canis vulpes, Linn.	*	N.S.	...	*	*	
—— *lagopus*, Linn.	...	A.	...	...	*	

IV. CONCLUSIONS.

The species recognized from the Ightham fissure may be divided into three groups:—1. The extinct forms. 2. Those which are extinct in Britain, but are still living elsewhere. 3. The species still living in Britain. Of the extinct forms only three or four have

been found in this fissure: *Rhinoceros antiquitatis*, *Elephas primigenius?*, and the new species of *Mustela* and *Mus*; but it must be remembered that the number of extinct mammals comprised in the Pleistocene fauna is comparatively small. Of the 48 species noticed by Prof. Boyd Dawkins in 1869, only 11 are extinct.

No doubt much uncertainty exists as to the exact time when some of the smaller mammals became extinct in this country, for unlike the larger animals (such as the urus) which were noticed by very early writers, such small forms as the northern vole and Arctic lemming would not attract attention, even though they should have continued in the country to much later times. It is unlikely, however, that species now restricted to steppe and Arctic conditions would have continued to live in Britain when the climate became temperate. Moreover, there is no evidence of their remains having been found in alluvial or other recent deposits. On the other hand, it is quite certain that the smaller mammals were more capable of adaptation to extreme changes of condition than were the larger ones. The field-mouse and some of the voles which lived in Britain in the times of the Norfolk Forest Bed are living here at the present day. Few, if any, of the larger species have been able to maintain their position; but this no doubt is largely due to the influence of man.

A mere glance at the list of species from the Ightham fissure shows how large a proportion of them are forms now living in the district (about 32), and these give so recent a look to the entire series that it may naturally be questioned whether this deposit is anything more than a recent accumulation. The fact that some extinct forms are found mixed with the recent species is not in itself a sufficient answer to this question. At first sight it seems quite possible for the extinct forms to have been derived from some Pleistocene deposit on the higher ground, which has now been entirely removed by denudation, and these, being gradually washed into this fissure from above, might have been re-deposited with the recent species in quite modern times. There are, however, two reasons which militate against this supposition; in the first place, if this were the correct interpretation, we should expect to find the two series of bones in a very different state of preservation, the derived bones being rolled and denuded; but such is not the case, for although one or two specimens have been partially dissolved, apparently by exposure to percolating water, the *Rhinoceros* teeth are as sharp and perfect as they can well be; the large *Rhinoceros* humerus shows no signs of having been worn, to any appreciable extent, since it was gnawed; the elephant foot-bone is likewise unworn. And, further, the skulls and bones of the small species, such as the lemmings and northern voles, which are not known to have lived in this country since Pleistocene times, are just as perfect as those of the recent species found with them. The second argument against the deposit being recent is derived from the physical conditions of the locality. This fissure is situated at the end of a small promontory on three sides

of which there is a stream, and the superficial area of the promontory is too small for the accumulation of water in sufficient quantity to carry in the larger specimens. Besides this, the fissure is open at one end to the valley, and in this condition could scarcely be filled with the deposit nearly to the top as it now is. If, on the other hand, it is contended that the filling of the fissure took place before the excavation of this valley, and consequently before the formation of the system of valleys of which this is only a part, it will be necessary to date back the formation of this deposit so far as practically to concede its Pleistocene age.

It seems possible that the fissure might have been partly filled in Pleistocene times, and that the recent species found their way in at a later date. If this were so, then the Pleistocene species should be found at the bottom and lower parts, and the living species at the top and higher parts; but such is not the case. When first Mr. Abbott began collecting these remains, it was only the upper part of the fissure which was accessible, and the specimens found were carefully kept by themselves; afterwards, at about halfway down, some *Rhinoceros* teeth were obtained, and subsequently other specimens were found at the lower part of the fissure. A list of the species from both parts was kept, but it soon became evident that the upper and lower parts yielded the same species. The living species occurred at the bottom as well as at the top, while the Arctic lemmings and northern voles were found near the top as well as in the lower parts. It is tolerably certain, therefore, that the deposit is of about the same age throughout. The possibility that in recent times the fox, badger, mole, and rabbit may have burrowed into the accumulated earth, and have left their remains in the burrows, to be mixed with the earlier forms, is a supposition that has been duly considered. In so far as the rabbit is concerned, this is probably correct, for the remains are not satisfactory and the species is not certainly known in Britain as a Pleistocene form. Some of the mole- and fox-remains might in like manner have found their way into the deposit, and the birds might have been carried in by the foxes. But if this view be accepted, it practically acknowledges the Pleistocene age of the mass of the deposit. There is, however, another standpoint from which to view the remains of the still living species. If we except the smaller birds, very few of which have been recognized in Pleistocene beds, nearly the whole of the remaining species in the foregoing list have been recorded from Cave-earth, or other Pleistocene deposits, in various parts of Britain, and several of the species extend back in time as far as the Norfolk Forest Bed.

Seeing, then, that there is in this fissure a fair number of the characteristic Pleistocene species (2 forms quite extinct, and 11 extinct in Britain though living elsewhere) mixed with living species which are known to have lived in Pleistocene times, there seems no reason for doubting the Pleistocene age of these representatives of living species; and it becomes highly probable that to the same period belong those other living species which are mixed

with them, but which have not before been recorded from beds of so early a date. I am disposed, therefore, to regard all the species found in this fissure, except the rabbit, as of Pleistocene age.

One of the most interesting species found in the Ightham fissure is the reindeer, which has also been met with at Boughton, Otterham, and Sittingbourne. It is a remarkable fact that although this species is abundant in the Thames Valley west of London, and has also been found both to the north and south of the lower parts of the Thames Valley, as well as in many Caves, it has never been met with in the brick-earth of the Thames Valley itself to the east of London. This circumstance, combined with the occurrence of *Rhinoceros megarhinus* in these deposits of the Lower Thames Valley, led Prof. Boyd Dawkins to regard the latter deposits as of an earlier date than those containing remains of reindeer, but without the megarhine rhinoceros; and while advocating for them a very early Pleistocene origin,[1] he acknowledged that they were certainly of later date than the Norfolk Forest Bed.

About thirty species of mammals have been found in the brick-earth of the Lower Thames Valley, and half of these occur in the Ightham fissure, but if Prof. Boyd Dawkins's separation of the former deposits as representing an earlier part of the Pleistocene be correct, then the presence of the reindeer at Ightham would prevent that deposit from being regarded as of the same age as the Lower Thames Valley brick-earth, and point to a relationship with some other part of that period. Indeed, there can be little doubt that, whatever may prove to be the relation of the Lower Thames Valley brick-earth to other Pleistocene deposits, the Ightham-fissure fauna is most nearly related to that which is found in British Caves.

Much interest attaches to a correct knowledge of the climate prevalent during the Pleistocene period, indications of which are to be found in the Arctic Freshwater Bed of Norfolk, the Boulder Clay, and the animals which are found in the various deposits. The probability of alternations of warmer and colder periods during Pleistocene times has long been advocated; but it has been thought possible by some that, with a more continental climate than at present prevails in Britain, the alternations of summer and winter might be sufficient to account for the seeming mixture of species. The latter supposition, however, seems scarcely tenable.

Recently the possibility of steppe conditions having extended much farther westward in Pleistocene times has been advocated by Dr. Woldrich,[2] by Dr. Nehring,[3] and my colleague Mr. Clement

[1] Quart. Journ. Geol. Soc. vol. xxv. (1869) p. 212.

[2] 'Die diluvialen Faunen Mitteleuropas,' Mitth. Anthrop. Gesellsch. Wien, vol. ii. 1882.

[3] 'Ueber Tundren und Steppen der Jetzt- und Vorzeit,' Naturwissensch. Wochenschrift, vol. v. (1890) pp. 451 and 475; see also separate work, published at Berlin, 1890.

Reid,[1] and it is interesting to see how far the material found at Ightham confirms, or militates against, such a possibility. The Arctic lemming and the Arctic fox are now restricted to the far north and to Arctic conditions. The voles, although some of them are living in temperate regions, all extend far to the north, and two of them (*Microtus ratticeps* and *M. gregalis*) are characteristic of desert or steppe conditions. The moles and shrews, though living in temperate countries, extend far to the north in Europe and Asia, and may well have existed in Britain in a cold or steppe climate. The species of bats which have been found likewise have a wide distribution, and most, if not all, range to 60° of north latitude. The common hare, which extends southward, is also found living in the north of Russia. The pika (*Lagomys pusillus*) is a Siberian and South Russian species, and with the *Spermophilus* is very strong evidence in favour of steppe conditions. The mammoth and woolly rhinoceros are known to have lived in the far north, although their recent representatives are tropical animals. The reindeer is now an inhabitant of the far north. The red- and roedeer have a wide range, but the latter is essentially a South European form. The brown bear and the common fox extend far into the north, while the Arctic fox, as already noticed, is found only in the northern icy regions.

The hyæna found at Ightham seems to be identical with the Pleistocene species, which is now living in tropical Africa, and is the one conspicuous form at Ightham which, when compared with the associated species, seems to be so strikingly out of its latitude. However, as is well known, there are species from other Pleistocene localities which seem likewise to indicate a warmer climate—namely, the lion, hippopotamus, and probably the remaining species of rhinoceros and elephant. But besides these must be noticed two other species not found at Ightham, which point in an opposite direction—namely, the musk ox and the Saiga antelope, one of which is altogether an Arctic species, while the other is just as definitely characteristic of the Steppes.

Whatever may be the cause, the Pleistocene fauna, as found in the Brick-earth, Gravel, and Cave-deposits, seems to be of a mixed nature, the species finding their nearest allies at the present day living under widely diverse climatic conditions. Some of the Pleistocene species thus indicate extreme cold, others point distinctly to steppe conditions, while a third series seems just as strongly to prove the prevalence of a warm climate.

These difficulties will doubtless eventually be removed, but in the meantime too much stress must not be placed upon the range of recent animals as an indication of that of the past, seeing that there are many circumstances besides climate which help to determine the distribution of species, circumstances concerning which we have, at present, but little information.

[1] 'Natural Science,' vol. iii. (1893) p. 367.

EXPLANATION OF PLATES X.–XII.

All are specimens from the Ightham fissure, and the figures are of the natural size unless otherwise stated.

Plate X.

Fig. 1. *Rana temporaria.* Humerus: *a*, front view; *b*, side view.
2. " " Biconcave penultimate vertebra, seen from below.
3. " " Left ilium, outer surface.
4. *Bufo vulgaris.* Right ilium, outer surface.
5. *Anguis fragilis.* Portion of investing bony scales.
6. " " Two scales, enlarged, showing broad edge overlapped by next scale.
7. " " Left ramus of lower jaw.
8. *Vipera berus.* Left ramus of lower jaw, wanting anterior end.
9. " " Vertebra, showing depressed articular cup.
10. *Alauda arvensis* (Skylark). Right humerus, front view.
11. " " " Right united metacarpals.
12. " " " Right tarso-metatarsus, seen from behind.
13. *Saxicola Œnanthe.* Left humerus, front view.
14. " " Right united metacarpals. (This figure represents the bone as too robust.)
15. *Larus?* Right humerus: *a*, front view; *b*, side view.
16. *Anas boscas?* Left humerus: *a*, front view; *b*, side view.
17. *Anas* ——. Left ulna.
18. *Buteo?* Left tarso-metatarsus, wanting distal end: *a*, outer surface; *b*, seen from behind.

Plate XI.

Fig. 1. *Sorex vulgaris.* Skull, side view. $\times \frac{3}{2}$.
1 *a*. " " Lower jaw, right ramus. $\times \frac{3}{2}$.
2. *Sorex pygmæus.* Skull, side view. $\times \frac{3}{2}$.
2 *a*. " " Lower jaw, left ramus. $\times \frac{3}{2}$.
3. *Vespertilio Nattereri.* Skull, seen from below. $\times \frac{3}{2}$.
3 *a*. " " Lower jaw, right ramus. $\times \frac{3}{2}$.
3 *b*. " " Femur, natural size.
3 *c*. " " Humerus, natural size.
4. *Lepus timidus.* Left femur, front view, natural size.
4 *a*. " " " " inner side.
5 *a*. " " Right humerus, front view.
5. " " " " inner side.
6. *Lagomys pusillus.* Lower jaw, left ramus.
6 *a*. " " Cheek-teeth. $\times 5$.
7. *Mus sylvaticus.* Lower jaw, right ramus, with one cheek-tooth.
7 *a*. " " Two lower cheek-teeth. $\times 5$.
8. *Mus Abbotti*, n. sp. Lower jaw, left ramus, with three cheek-teeth.
8 *a*. " " Cheek-teeth of same. $\times 5$.
9. *Myodes lemmus.* Lower jaw, left ramus, front cheek-tooth restored from another specimen.
9 *a*. " " Grinding surfaces of cheek-teeth. $\times 5$.
10. " *torquatus.* Lower jaw, left ramus.
10 *a*. " " Grinding surfaces of cheek-teeth of same. $\times 5$.
11. *Microtus* (*Arvicola*) *ratticeps.* Lower jaw, right ramus, with two cheek-teeth.
11 *a*. " " " Grinding surfaces of cheek-teeth of same. $\times 5$.
12. " " *gregalis.* Lower jaw, left ramus, with three cheek-teeth.
12 *a*. " " " Grinding surfaces of cheek-teeth of same. $\times 5$.
13. *Rhinoceros antiquitatis.* First, or front, upper deciduous milk-molar.
14. " " Third milk-molar.
15. " " Fourth milk-molar.

Fig. 16. *Rangifer tarandus.* Part of lower jaw, right ramus, with two milk-teeth in place.
16 *a.* ,, ,, The two teeth seen from above.
17. *Mustela robusta*, n. sp. Left humerus, front view.
17 *a.* ,, ,, Same bone, outer side.
18. ,, ,, Right ulna, inner side.
19. ,, *vulgaris*, var. *minuta.* Lower jaw, right ramus.
20. ,, ,, ,, Left tibia, front view.

PLATE XII.

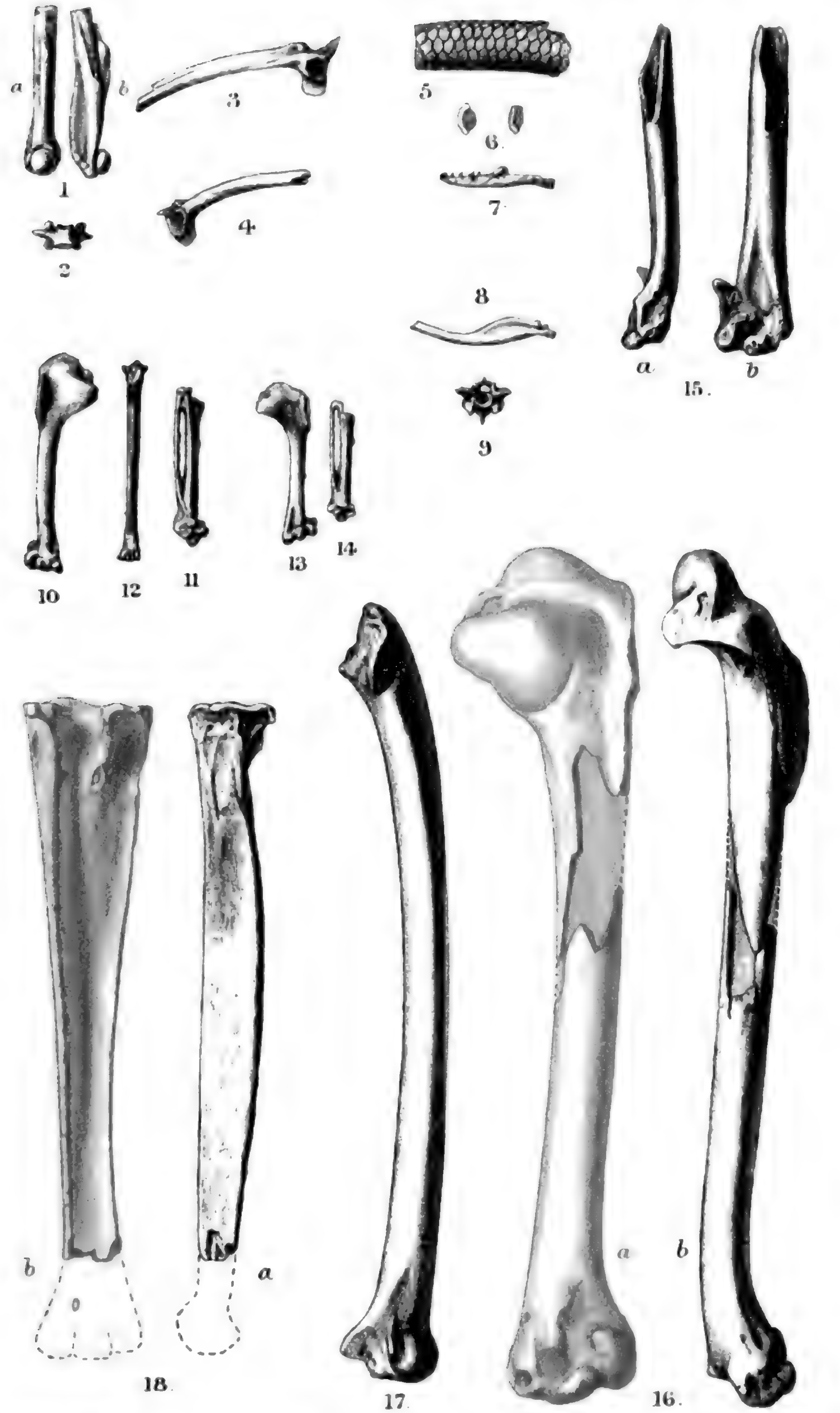
Fig. 1. *Canis vulpes.* Right femur.
2. ,, ,, Right humerus.
3. ,, ,, Right mandibular ramus.
3 *a.* ,, ,, Teeth of same, seen from above.
4. ,, ,, Right upper jaw.
5. ,, *lagopus.* Left femur.
5 *a.* ,, ,, Same bone, inner view.
6. ,, ,, Tibia.
6 *a.* ,, ,, Same bone, proximal articulation.
6 *b.* ,, ,, Same bone, distal articulation.
7. ,, ,, Right humerus.
7 *a.* ,, ,, Same bone, inner side.
8. ,, ,, Left mandibular ramus.
8 *a.* ,, ,, Teeth of same from above.
9. ,, ,, Right upper jaw.
9 *a.* ,, ,, Same, palatal view.
10. *Ursus arctos?* Left fifth metacarpal.
11. *Hyæna crocuta?* Canine tooth, much denuded.

DISCUSSION (on the two preceding Papers).

The PRESIDENT said it was greatly to be regretted that Mr. Abbott was unable to be present at one of the best-attended meetings of the Session.

Mr. TOPLEY compared the fissures filled with loam and gravel, and containing mammalian bones and land-shells, of the Maidstone district with the interesting example now described, and explained that those of the Maidstone Rag country were connected with overlying deposits of drift, the material now filling the fissures having been let down into the rock by solution of the limestone along joints and cracks. He now thought that some of the wider pipes of brick-earth of the Maidstone area may be partly due to slipping of the rock over the Atherfield Clay below, letting down the overlying drifts bodily into the long spaces thus formed. The numerous fissures near Maidstone had been so carefully noted by the late Mr. Bensted and his son during many years, that it seemed unlikely that such interesting deposits of bones as Messrs. Abbott and Newton now described could have been there overlooked. The Boughton 'fissure' or 'cave,' described by Buckland and referred to by Murchison, was not near any important deposit of drift, and this fissure more resembled that at Ightham; the latter probably somewhere had communication with the surface.

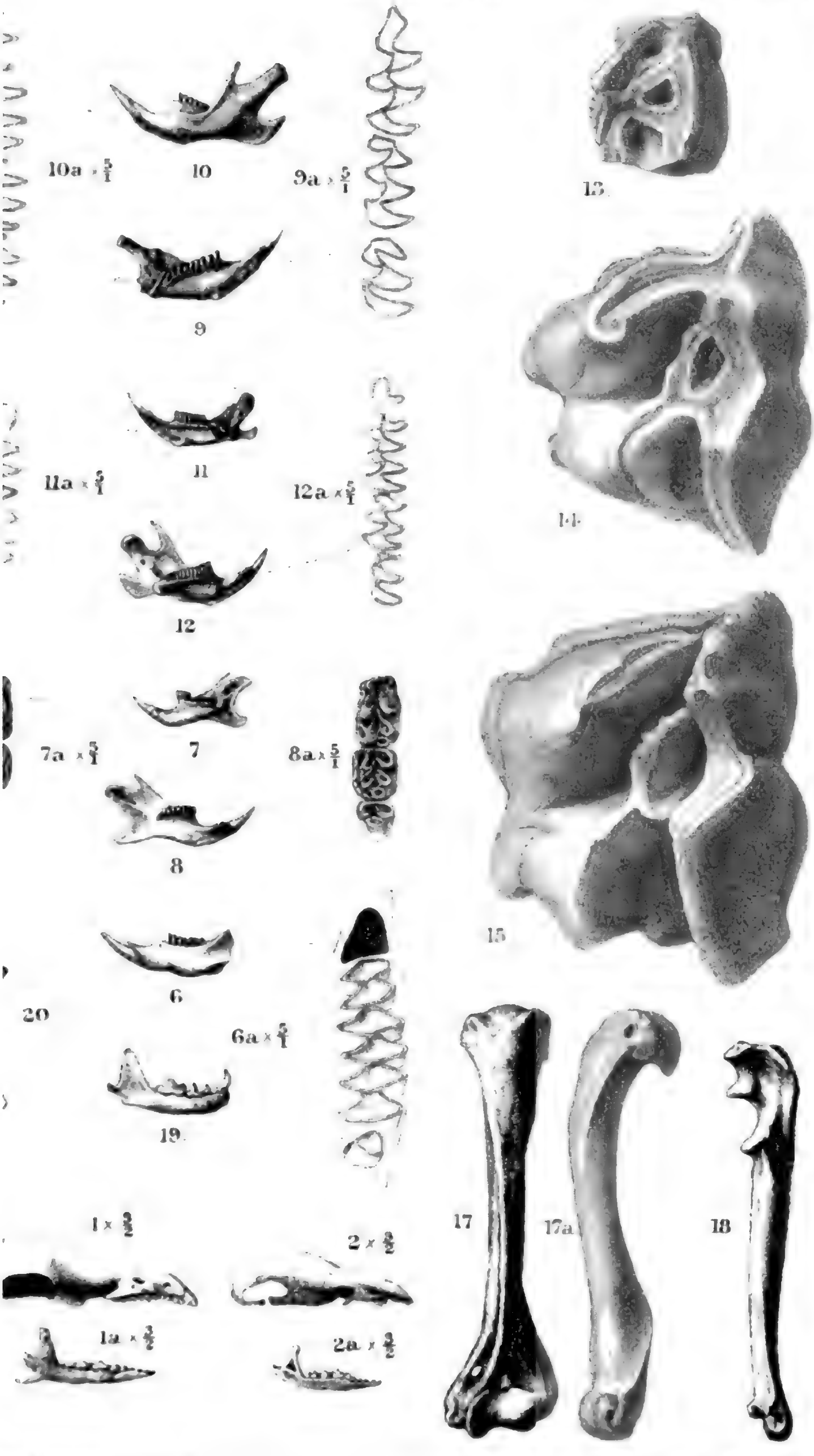
Mr. Topley referred to a diagram exhibited by the Author illustrating his views as to a reversal of drainage in the Shode Valley area: the higher gravels having been formed by a stream which flowed northward towards the Darent from the Lower Greensand escarpment, which then stretched far to the south over



A. T. Hollick del. et lith.

Mintern Bros. imp.

AMPHIBIA, REPTILES & BIRDS FROM IGHTHAM.



8. UNGULATES. 17–20. CARNIVORS.
HAM.

Mintern Bros. imp.

the Weald Clay. He was not at present (nor was Prof. Prestwich) prepared to accept this view, although there are many difficulties in explaining the origin of gravels near the existing watersheds; but similar difficulties occur in other parts of the Wealden area.

Sir Henry Howorth desired to express his admiration of the work of Mr. Abbott. While Dupont at Brussels and Nehring at Berlin have been carefully working out the remains of the small mammals found in the Pleistocene beds and the caves of those countries, we have done little in this respect since Sanford and Dawkins's exploration in the West of England, our attention having been largely limited to the larger mammals. The careful and laborious work of Mr. Abbott and Mr. Newton on the products of this fissure had therefore removed an opprobrium from English geology.

The tooth of the hyæna on the table was labelled *crocuta*, which doubtless means the old *H. spelæa*. To call it *crocuta*, unless the attribution is quite certain, is somewhat dangerous; but Mr. Newton seemed to identify it with *H. brunnea*, a very different beast with a very different history. He (the speaker) had a great dislike for the formation of new species on insufficient evidence. In a genus so variable as *Mustela* it would be well to compare these bones with skeletons of the fitch and other American living species, before burdening our lists with a new name on the ground of a somewhat larger size in the bones merely.

In regard to Mr. Abbott's theoretical views, he could not believe that these bones were carried into the fissure by river-action. Any river powerful enough to have carried along with it the large pieces of mammoth and rhinoceros-bone would have scoured the fissure of all these minute bones, which showed no trace of breakage or of wear. The absence of fish-bones and of fluvial molluscs, and of the ordinary wreckage of a river, were strongly against the view. On the other hand, the presence of bones gnawed by hyænas, the occurrence of so many frogs' bones and the bones of bats, most unlikely animals to be found in a river-bed, pointed to the so-called fissure having been a cave. The beautifully sharp and unweathered condition of the bones also showed that they were not exposed to the air even for one season, but had been carefully protected by a roof. It was such an assemblage as we should expect in a hyæna-den which was also frequented by large owls that fed on the small rodents, the frogs, etc., and also by bats. Hence also the great variety of species which marks the larder of some raptorial beasts and birds.

If a cave, as he would certainly maintain, the question of how the bones were found as they occurred involved a great many considerations, which he had discussed at great length in the chapter on Caves in 'The Mammoth and the Flood' and which there was not time to discuss now.

Dr. Henry Hicks also spoke.

Mr. E. T. Newton, in the absence of Mr. Abbott, thanked the Society for the cordial reception accorded to both their papers, and, in reply to remarks by Sir H. Howorth, said that the balance of evidence was in favour of the hyæna's tooth belonging to *Hyæna crocuta*.

16. *On the* Relations *of the* Basic *and* Acid Rocks *of the* Tertiary Volcanic Series *of the* Inner Hebrides. By Sir Archibald Geikie, D.Sc., LL.D., F.R.S., F.G.S. (Read February 21st, 1894.)

[Plates XIII. & XIV.]

Contents.

I. Introduction.

Before entering upon the special subject of the present paper, I wish to be permitted to make certain personal explanations which appear to me to be necessary on this occasion. Having in my early years had the good fortune to spend much time among the Western Islands of Scotland, I was soon fascinated by the geological features of that picturesque region. Like most young geologists, I began with the fossils and collected largely from the Jurassic formations of Skye and the adjacent islands, though the interesting problems presented by the general structure of the area, and more particularly by the igneous rocks, could not wholly escape the attention of an enthusiastic beginner. The results of these youthful labours were eventually communicated to this Society in the year 1857.[1]

Having been appointed to the Geological Survey in 1855, I had the inestimable advantage of a practical training in methods of detailed geological mapping, and it so happened that this training lay, in large measure, among the ancient volcanic rocks so copiously developed among the Old Red Sandstone and Carboniferous formations of Central Scotland. I was thus led from the very outset to take a keen interest in volcanic geology, and the experience gained among the records of Palæozoic eruptions induced me to return to the study of the latest series of volcanic outbursts in Britain—those of the Western Isles. From time to time I communicated to the Royal Society of Edinburgh accounts of my investigations.[2] At last, in the year 1871, I had advanced far enough to be able to present to the Geological Society a general outline of the Tertiary volcanic history of Britain.[3] I therein endeavoured to show how extensive in area, varied in petrographical character, and protracted in geological time were the Tertiary eruptions within the area of our islands. This paper was intended to be the first of a series,

[1] Quart. Journ. Geol. Soc. vol. xiv. p. 1, 'On the Geology of Strath, Skye.'

[2] See in particular Trans. Roy. Soc. Edin. vol. xxii. (1861) p. 649; Proc. Roy. Soc. Edin. vol. vi. (1867) p. 71; also Brit. Assoc. Rep. 1867, Sections, p. 49.

[3] Quart. Journ. Geol. Soc. vol. xxvii. p. 279, 'On the Tertiary Volcanic Rocks of the British Islands.—First Paper.'

but as I could only snatch a few brief weeks of annual holiday for this extra-official work, my progress could not be rapid. Before I was able to offer to the Society my second communication, Prof. Judd, at the beginning of 1874, read before the Society a memoir 'On the Ancient Volcanoes of the Highlands.'[1] As he had been so fortunate as to be enabled to devote many months of continuous labour to the investigation of the region, he succeeded in covering the ground which I meant to occupy. In the belief that in a large part of my own undertaking I had thus been forestalled, I laid aside the design of continuing the series of papers already begun in our Journal.

Prof. Judd's paper was undoubtedly a bold and brilliant piece of work. Though he had had no previous experience of igneous rocks, he gathered together a large series of observations and generalized from them so ingeniously and suggestively that his memoir attracted a large amount of notice. And yet, from my own experience in these Western Isles, I knew that there were many difficulties which he had not explained. It was not, however, until the year 1879 that, in the course of a journey through some of the volcanic tracts of Western America, I began to see, as I believed, the meaning of some of the phenomena which had for so many years puzzled me in the West of Scotland. My old love of the subject and of the scenery of the Inner Hebrides was re-kindled, and then, in these wilds of the Far West, I determined to take up once more the study of the history of our Tertiary Volcanoes. At such intervals of leisure as could be seized in the midst of a busy official life, I worked at the subject and, after nine years, was enabled to complete my task.

So long a period of time had elapsed—no less than seventeen years—since the publication of my paper on Tertiary Volcanic Rocks in our Quarterly Journal, that it was obviously undesirable to attempt to resume the series of which that paper was intended to be the first. I therefore turned to the Royal Society of Edinburgh, which had published my earliest writings on the subject, and offered to it a somewhat voluminous monograph. The Council of that Society accepted my communication, and published it in its 'Transactions' during the autumn of 1888.[2]

In retracing my former footsteps among the Inner Hebrides and in traversing fresh ground, I was led to form conclusions very different from some of those which had been arrived at by Prof. Judd. It is not necessary for my present purpose to enumerate these differences of opinion; I will allude to one only, perhaps the most important of all, inasmuch as it affects the whole order of interpretation of the volcanic history. Prof. Judd, as I found from copious evidence collected all over the region, had mistaken the true sequence in the protrusion of the volcanic masses of the Inner Hebrides, putting the great bosses of acid rocks at the beginning instead of at the end of the series. It would have been to me

[1] Quart. Journ. Geol. Soc. vol. xxx. p. 220.
[2] Trans. Roy. Soc. Edin. vol. xxxv. pp. 21–184.

an exceedingly distasteful task to indicate all the points in regard to which I thought him to be in error. But it was impossible to avoid reference to the more important of them where general principles or important deductions were at stake. The indication of my dissent from his views was done as lightly as possible; I referred to his writings more frequently when I could do so in agreement with him than where I differed from him, and I feel confident that no one who had not previously made himself master of the subject would ever imagine from reading my memoir that the differences of opinion between us were so profound as they really are.

As my memoir was based on detailed observations over the whole volcanic region, prolonged through a series of years, during which I repeatedly re-examined some parts of the ground, any adequate criticism of it could only be founded on a careful study of some of the numerous sections cited by me. Without waiting, however, for the opportunity of testing the value of my deductions by an examination of the field-evidence from which they were drawn, Prof. Judd at the beginning of 1889 communicated a general criticism of my paper to this Society.[1] In the discussion which followed the reading of his paper I briefly replied. But, as it appeared to me that no valid arguments had been adduced by him against either my facts or my conclusions, I refrained from entering into further controversy.

In a subsequent paper, on 'The Propylites of the Western Isles of Scotland,' Prof. Judd affirmed that "the great cause of the conflict of opinion between us concerning the relations of the igneous masses of the Western Isles of Scotland is to be found in the different interpretation we place on these propylitic rocks."[2] Though this statement appeared to me to convey a very erroneous representation of the actual difference of opinion, I declined to make any reply. The main fundamental facts of geological history on which we differed remained quite clearly defined, and, in spite of the array of petrographical learning brought forward by him, he seemed to me to leave my version of the true sequence of events in the volcanic history absolutely as it was. Disliking controversy so thoroughly as I do, I even refrained from replying to what I regarded as misconceptions or misstatements of my views, being content to abide the verdict of competent geologists, who would doubtless review the evidence on the ground.

My critic has now returned a third time to the attack in the paper which he read to the Society on the 25th of January, 1893.[3] He therein brought forward some observations made by him among the Cuillin Hills of Skye, which he contended finally established the correctness of his opinion that the granitic protrusions of the Tertiary volcanic series are older than the gabbros. Instead of trying, however, to rebut the mass of cumulative proof drawn by me from all parts of the volcanic area, that the granitic bosses are younger than the other rocks because they break through them and send veins into

[1] Quart. Journ. Geol. Soc. vol. xlv. p. 187.
[2] *Op. cit.* vol. xlvi. (1890) p. 353. [3] *Op. cit.* vol. xlix. p. 175.

them, he ignored that overwhelming evidence, not making even an allusion to its existence, and proceeded to refer to a single locality, one which I had specially cited as affording ample proof of my statements, but where he affirmed that he had found blocks of Tertiary granite in the gabbro. The occurrence of these blocks, he actually affirmed, now settled the question beyond further dispute in his favour. In the debate that followed the reading of the paper, adverting to this extraordinary method of reasoning, I affirmed that the structures described by him as occurring in his 'inclusions' seemed rather to point to intrusive veins, but that even if the 'inclusions' were actually detached and enclosed blocks, they could not justify the sweeping deduction that he drew from them, and could not for a moment be held to invalidate the copious evidence brought forward by me from the whole volcanic region, and even from the very locality now in question, that the acid rock actually cuts through the basic masses. Even if the so-called 'inclusions' were enclosed blocks of granite, how could Prof. Judd suppose that a few such blocks from one little ridge were to disprove the definite testimony of scores of sections cited from all parts of the region? I contended that until that testimony was examined and disproved it was idle to bring forward such statements and reasoning as appeared in his paper.

Possibly I might once more have remained content with a verbal reply printed in the report of the debate in our Journal. But, while his paper was passing through the press, Prof. Judd added a postscript wherein he expressed himself in such a way as to leave me no choice but to defend my fair fame. He says that he omitted all reference to "the alleged existence of veins proceeding from the granite into the gabbro" from "a desire not to complicate the very definite issue raised in the title of this paper." One would suppose that less complication would have been likely to arise had he refrained from introducing a fresh kind of evidence and a novel mode of argument until he had disposed of the definite statements already opposed to him. He then asserts: "I can only add that, since this assertion [that veins of granite cut the gabbro] was made, I have revisited all the localities referred to, but have never succeeded in finding true granite-veins penetrating the gabbro. It was, in fact, while vainly engaged in searching for such veins that I discovered the very conclusive evidence of the inclusions described in this paper. It appears to me that the existence of these inclusions of granite in the gabbro is absolutely irreconcilable with the occurrence of veins of the same granite cutting through the gabbro."[1]

In consequence of these remarks, though I felt that they could be conclusively answered at once, I deemed it best to re-examine the locality in Skye before making any reply. I have since traversed the ground very carefully, and I now lay the results of this re-examination before the Society.

I propose to show that my published account of the relations of

[1] *Op. cit.* p. 194.

the gabbro and granophyre at Meall Dearg, in Glen Sligachan, Skye, which is disputed by Prof. Judd, was accurate: that the granophyre (or granite) there sends abundant dykes and veins into the gabbro; that Prof. Judd's so-called 'inclusions' are, as might have been surmised, portions of these dykes and veins; and thus that the evidence which he has adduced affords additional and crushing testimony to the truth of my observations. When he was opposing the deliberate statements of a previous observer, it was surely his bounden duty to examine the alleged facts, on the ground, with scrupulous diligence. I regret that I must now show that he has failed in this duty, for, had he used even the most ordinary care, it is incredible that he could have missed the evidence on which I relied. That geologists may be able to judge between us, I have had some of the visible sections photographed, and I appeal to the impartial testimony of the camera in my favour. The evidence from this Skye locality is so abundant and conclusive, and the point to be proved is so simple and elementary, that I cannot help feeling as if some apology were due to the Society for the necessity of bringing the subject before it.

II. The Gabbro Bosses.

The tracts of gabbro among the Western Isles have not yet been traced out in detail upon maps of a large scale. Until that task is completed it will hardly be possible to show how complex these areas are, alike in their tectonic and petrographical features. I have referred to this complexity in my memoir already cited, and have given the evidence which indicates that the larger bosses were probably the results of many successive protrusions.[1]

The ridge referred to by Prof. Judd as Druim an Eidhne, the site of his 'inclusions,' is marked on the 6-inch Ordnance map as forming the south-eastern portion of a rugged spur which, descending from the crags overlooking Harta Corry, is crossed by the footpath to Coruisk. On the map accompanying his paper Prof. Judd inserts his 'enclosures' only on that limited portion of the ridge, but he would have found that the evidence on which he relied extended much beyond the narrow limits to which he has restricted it. Indeed, the most striking evidence of the occurrence of granitic material within the area of the gabbro lies to the north of these limits.

The whole ridge which ascends from the hollow of Strath na Creitheach between the two lochs, and, including the Druim an Eidhne, rises into the rugged ground that bounds the eastern side of Coire Riabhach, affords an admirable illustration of the really complex nature of the gabbro bosses. Instead of being composed of one rock belonging to one great interval of eruption, it includes at least five varieties, exclusive of the granophyres, indicating a succession of emissions. These rocks are not disposed at random, but exhibit a certain roughly-bedded arrangement. Conspicuous

[1] Trans. Roy. Soc. Edin. vol. xxxv. (1888) p. 140.

are the alternations of a dark, fine-grained, massive rock, which under the microscope shows a gabbro-like structure, with remarkably banded and much coarser varieties of gabbro. These varieties of rock follow each other in rude beds, which run in a general N.N.W. direction. I shall on another occasion describe in more detail the remarkable structures of the banded gabbros, which have a suggestive bearing upon the origin of the structures in some of our oldest gneisses.[1] It may be sufficient to state here that the banded sheets, as well as those of finer material with which they are intercalated, have a general easterly dip, but sometimes curve round so as to incline towards S.S.E., the angle of dip being usually above 20° (see fig. 1, p. 222). The remarkable segregation of the component minerals of these banded sheets into lenticular laminæ gives them a strikingly gneiss-like aspect (Pl. XIII.). This structure continues up to the very edge of the granophyre, where it is abruptly truncated.

These rudely bedded and banded gabbros are traversed by veins and sills of a remarkably coarse and massive form of gabbro. Another abundant variety consists of pale, more felspathic material, which, taking the form of veins and strings, traverses all the other gabbros. These pale veins obviously belong to the gabbro series, to which, under the microscope, their affinity is abundantly clear. They are the 'white veins' referred to by Prof. Judd in his postscript as easily distinguishable from apophyses of a granite. But they are not the veins described by me as proceeding from the granite (or granophyre) at this locality.

One of the most remarkable constituents of the gabbro ridge is a large mass of coarse agglomerate, which forms a group of knolls and crags among the gabbros, its eastern margin being truncated by the tolerably straight boundary of the granophyre. It contains abundant blocks of various slaggy lavas like those of the basalt-plateaux.[2] Dykes of fine basaltic material intersect the agglomerate and the gabbros.

[1] In various papers Prof. Judd has repeatedly asserted that I went so far wrong in my work among the volcanic rocks of the Western Isles as to mistake the gabbros for Laurentian gneiss. My error never went further than a suggestion, which, however, I thought at the time probable. The suggestion was made in a very guarded way in a footnote on p. 210 of the first edition of my 'Scenery of Scotland,' published in 1865:—'If the hyperstheue rock of the Cuillin Hills of Skye belongs to this ancient formation' [Laurentian gneiss]. I had never had an opportunity of carefully studying the rock, and therefore never described it in any of my writings. But I had in my early years in Skye crossed some parts of it, and had been astonished by its gneiss-like aspect. Any geologist who is familiar with the Lewisian gneiss, and sees for the first time the banded gabbros of the Cuillin Hills, will readily appreciate how I should have been led from only cursory examination to connect the gabbro with metamorphic rocks. The publication of Prof. Zirkel's paper in 1871 (Zeitschr. Deutsch. geol. Gesellsch. vol. xxiii. p. 1)—that is, three years before Prof. Judd entered the ground—completely satisfied me that the gabbros were part of the Tertiary volcanic series.

[2] There are probably many scattered masses of agglomerate among the Cuillin Hills, which will be found when the ground is mapped in detail. There must be at least one in the basin of Harta Corry, and a mass of the rock occurs at the head of Corry na Creiche.

Thus the important fact is established that the ridge of which Druim an Eidhne forms part consists of a varied group of volcanic rocks belonging, not to a single eruption, but to a succession of eruptions. All these various constituents of the ridge successively abut against the edge of the granophyre. Each of them in turn is abruptly truncated along the line of contact with the acid material. This truncation is made particularly distinct by the way in which the parallel structure of the banded gabbros, which so much resembles bedding, is sharply cut off. The ends of the beds and laminæ disappear as suddenly as the ends of a series of shales traversed by a basalt-dyke (fig. 1, p. 222).

It is inconceivable that this truncation could ever have taken place had the gabbro been an intrusive mass erupted through the granophyre. It can only be explained in one or other of two ways: either the granophyre has been faulted against the complex basic assemblage of the ridge, or has broken across it as an eruptive protrusion. The supposition of a fault is at once negatived by the most cursory examination of the ground, as will be seen from the evidence which I now proceed to state.

III. The Granophyre Bosses.

There can be no doubt that though, on the whole, simpler in structure and more uniform in petrography than the gabbros, the acid bosses are more complex than their external conical forms would lead us to suspect. Even within the limits of a single continuous area, like that of the Red Hills of Skye, indications may be found of successive protrusions of material, not always of precisely the same lithological character. But until the structure of the ground has been traced upon large-scale maps no satisfactory account of these details can be given.

The granophyre mass which abuts against the great ridge of basic rocks above described may be taken as fairly typical of the Tertiary acid protrusions of the Western Isles. It rises northward into the prominent height of Meall Dearg (the red rounded hill), which from the north seems to close in the upper end of Glen Sligachan, and owing to its bright reddish-yellow colour offers a striking contrast to the dark gabbro crags that rise behind it and on either side. The line of junction between the acid and basic rocks, so far as it can be observed, is vertical. This is best seen in the ravine which descends from the western shoulder of Meall Dearg into the mouth of Harta Corry. To the south of Meall Dearg the basic rocks rise as a low, rugged, sometimes mural, crag from the summit of the long talus of broken-up granophyre, and seen from a distance present the deceptive appearance of an overlying cake.[1] A little careful search among the débris and projecting knobs of rock along

[1] It was, I have little doubt, such sections as this that gave the impression that the granitoid rocks underlie and are older than the gabbros. But if, instead of looking at the rough mountains from a distance, a geologist will climb their sides, he can easily satisfy himself as to the true nature of the junction-line between the two rocks.

the base of the cliffs shows that the verticality of the junction-line continues southward. The same relation can be followed on the opposite side of Strath na Creitheach and along the precipitous front of Garbh-bheinn.

The rock of Meall Dearg and of the declivities lying to the south of that eminence displays the drusy, micropegmatitic structure so characteristic of the granophyres of the Inner Hebrides. But one new feature of interest has been observed in it which deserves mention here. While examining under the microscope some thin sections of this rock, Mr. Teall has discovered that it contains the mineral riebeckite. At my request he has been so good as to draw up the following note on the subject:—

"The rock is medium-grained, light-coloured, and contains drusy (miarolitic) cavities. The principal constituent is a micropegmatitic intergrowth of quartz and orthoclase, but more or less idiomorphic crystals of the same minerals occur. The felspathic portion of the micropegmatite, which usually surrounds the idiomorphic orthoclase, extinguishes simultaneously with the central crystal. There are small irregular patches, opaque or nearly so by transmitted light, and brown by reflected light. These may represent in some cases corroded biotite. Extremely thin opaque black plates (? ilmenite) and riebeckite are the only other minerals present, and these appear sparingly.

"The riebeckite occurs in the well-known spongy forms, and sometimes as idiomorphic crystals, or rather as crystals which are idiomorphic in the prismatic zone. The usual forms are those of the prism {110}, but in one case the clino-pinacoid {010} was also observed. The a axis is most nearly coincident with the vertical axis, and the pleochroism is as follows:—

a and β deep blue;
γ greenish brown.

"Sauer gives green as the colour from rays vibrating parallel to γ, and Harker brown. The determination of the colour in this case would probably vary with different observers and with the thickness of the section; but there can be no doubt as to the presence of an olive-green tinge in this mineral when viewed by rays vibrating parallel with γ."

As may be commonly observed among intrusive rocks of all ages and compositions, the granophyres of the Inner Hebrides become finer-grained towards their margin. They assume sometimes even a felsitic texture and exhibit flow-structure and well-developed spherulites. These characters occur altogether independently of the nature of the adjoining rock. Thus in Mull they may be seen where the acid rock impinges upon the bedded lavas of the plateaux and upon the intrusive gabbros. In Raasay they are well exhibited where the protrusions have taken place among Jurassic sandstones and shales. Such well-known phenomena of contact are often of service in distinguishing truly intrusive rocks.

These marginal structures are exhibited along the whole length of the junction-line of the granophyre with the basic rocks of the ridge from the western slopes of Meall Dearg southward. The granophyre, as it approaches that junction-line, becomes fine-grained or felsitic in texture, showing here and there abundant spherulites ranged in rows along the lines of flow-structure, which are sometimes remarkably well developed and run parallel with the edge of the rock. In the ravine on the west side of Meall Dearg, where the vertical line of contact between the basic and acid rocks has been so well exposed, the perpendicular rows of spherulites run up the bare faces of granophyre.

It is important to observe that, at this locality as elsewhere, no dependence whatever can be found between these marginal structures in the granophyre mass and the various rocks of the ridge against which they abut. The spherulites, for instance, are to be seen just as well in the acid rock where it impinges on the agglomerate as where it lies next to coarse massive gabbro. There is, indeed, nothing unusual in this feature; on the contrary, it is exactly what any geologist acquainted with the behaviour of intrusive bosses would have expected. Prof. Judd speaks of having observed the spherulitic structure and felsitic texture "at one or two points" along the junction-line of the basic and acid rocks, but he makes no further reference to this observation. He apparently groups these marginal structures with those of his 'inclusions,' regarding them as due not to the more rapid cooling of the outer shell of the granophyre, but to the re-fusion of that rock from the protrusion of the gabbro through it. Whether fusion on so large a scale could have been effected in a solid mass of granite by the breaking through it of a continuous body of gabbro is obviously open to grave question. To assert that structures which are common characteristics of the marginal portions of bosses, sills, and dykes are in this instance produced by re-fusion, and thus that what by the ordinary laws of evidence would be set down as the older rock is here really the newer, surely demands specially cogent and copious proof. But even if we grant that a large mass of gabbro disrupting a previously solidified granite might possibly induce upon it these marginal structures, is it conceivable that a complex assemblage of basic rocks, successively injected in thin sills and narrow dykes through each other, such as I have shown to constitute the ridge north of Druim an Eidhne, could have produced such effects? Is it to be supposed, too, that the agglomerate exercised the same melting influence on the rock next to it, which, as I have shown, presents just the same structures? In short, even were there no other evidence than this fine-grained felsitic and spherulitic margin, this, I submit, would be in itself sufficient to prove that the granophyre has broken through the gabbro.

The structures so well exhibited on the periphery of the granophyre are not, however, confined to that part of the mass. On the rocky slopes south of Meall Dearg, close to the edge of a gully cut by the southern fork of the stream which drains that hillside, a

prominent rib may be observed rising amid the ordinary granophyre. It consists of a spherulitic fine-grained material forming a band about 10 feet broad, which may be traced under the débris for several hundred yards up the hill in a direction slightly north of west. It exhibits the same beautiful flow-structure with spherulites as is seen in the marginal part of the granophyre boss. The spherulites, often an inch or more in diameter, are set in rows along the lines of flow-structure, which run parallel to the direction of the rib. The absolute identity of these structures with those which I have described and with those also of the dykes and veins to be immediately referred to, including those of the so-called 'inclusions,' is so obvious that there cannot be any room for hesitation in classing them all together as having one common origin. The presence of a band of spherulitic granophyre or felsite in the main body of the granophyre, at a distance of 1000 feet from the edge of the gabbro, cannot be accounted for by any fusing effect of the basic rock. Like the marginal zone of finer grain, this internal dyke-like rib obviously represents a phase in the consolidation of the great protrusion of acid material, though its production may have been somewhat later than that of the marginal zone and its offshoots.

I now proceed to show that the great granitic eruption of Glen Sligachan has been accompanied by the injection of dykes and veins into the adjacent rocks, as formerly affirmed by me. About half a mile south from the top of Meall Dearg, and thus well to the north of the locality at which Prof. Judd has shown the position of his 'inclusions' on his map, the low gabbro cliff, where it overlooks the sources of the streamlets that run down the declivity below, is interrupted by several hollows which allow of an easy ascent to the summit of the ridge. On examination it is found that these interruptions in the line of cliff are due to breaks in the continuity of the various beds and veins of different gabbros, and to the divergence of dykes of granophyre from the main body of that rock. Three such interruptions may be observed within a horizontal distance of 90 yards (fig. 1, p. 222). Each of these marks the position of a dyke which can be followed from the spherulitic margin of the granophyre with which it is continuous and of which it forms an offshoot.

The most northerly of the three dykes (I.) is about 9 feet wide where it issues from the main mass of granophyre. Weathering more easily than the basic rocks through which it runs, it occupies the bottom of a long hollow of which the various sheets of gabbro form the craggy sides. But it protrudes at numerous points from under the turf, and by means of these projections can be followed in a nearly straight line in a S.S.E. direction for 800 feet, when it is lost beneath herbage and masses of gabbro.

The second dyke (II.), from 6 to 8 feet broad as it leaves the granophyre mass, runs parallel to the first at a distance of about 30 yards from it, and can be traced for 200 feet or more southward across the gabbro. There is in this case also no difficulty in following along the line of straight hollow the protruding knobs,

demonstration of this assertion I produce a photograph (Pl. XIV.) of the second example (II). The camera, when this view was taken, was planted on the main mass of granophyre which, with its marginal lines of flow-structure and rows of spherulites, could be followed up into the dyke. The vertical walls of the dark-banded gabbros are here clearly exhibited, with the pale dyke of acid rock rising between them.

But it is not enough to say that the granophyre sends apophyses into the gabbro. The fact of the intrusive character of the acid rock is rendered still more striking by the arrangement of the various beds and veins of the complex mass of basic materials across which the dykes have been intruded. In fig. 1, wherein I have tried to express diagrammatically the parallel banding of the gabbros, it will be seen that the successive basic sheets, dipping in a south-easterly direction at from 20° to 35°, are cut through by the dykes. There is thus a double truncation of the bedding and banding of the gabbros. These structures are abruptly cut off by the vertical wall of the granophyre boss in a general W.N.W. direction, while they are further intersected in a N.N.W. direction by the dykes. No more conclusive evidence could be given of the fact that the granophyre has been protruded after the last of the successive eruptions of gabbro.

I have instanced first some cases of apophyses which can actually be seen to diverge from the granophyre mass of Meall Dearg. But there are numerous veins and dykes of exactly similar material which traverse the various rocks of the gabbro ridge, but of which the direct connexion with the main body of the acid rock cannot be observed. These detached portions may be seen all over the ridge, and even on its western front, looking down into the deep hollow of Coire Riabhach. They lie between the dykes I have described and the Druim an Eidhne, where they are frequent, continuing southward beyond the Coruisk footpath. Except that they cannot be directly traced to the granophyre and that their visible portions are comparatively short, many of them are in every respect repetitions of the dykes which can be seen to issue from the body of the acid rock. Indeed, it seems to me probable, as above suggested, that some of them are really prolongations of these dykes, rising once more to daylight. But that, in any case, they are true veins or dykes of later date than the basic materials amid which they lie is abundantly manifest from their form, their internal structure, and the manner in which they intersect the surrounding rocks.

These detached masses are long and narrow strips, like the dykes just described. They vary up to 6 or 8 feet in breadth, and can be followed continuously for variable distances, often for 20 feet or more. They display, exactly as the dykes do, a fine-grained texture, beautiful flow-structure, and rows of spherulites. Moreover, the flow-lines follow faithfully the irregularities of the bounding walls of gabbro, curving round projections with the sweeping and sometimes curling lines so characteristic of rhyolitic streams. Nowhere,

indeed, among the igneous rocks of this country are there to be found more striking examples of these flow-structures and spherulitic lines than at this locality in Skye.

Now, it will hardly be believed, but is nevertheless true, that these obvious veins and dykes, repeating down to the minutest details the structures of the dykes which can be traced from the granophyre for many yards across the gabbros, are the 'inclusions' described by Prof. Judd. His account of the shape of his 'inclusions' is somewhat vague. He speaks of "a number of irregular patches of pale granitic rock" forming "depressions in the basic rock which are usually filled with débris; some of the patches show a section several square yards in area." He makes no allusion to the constant linear form of his patches and to the parallelism of their flow-structure and rows of spherulites with their bounding walls; nor does he seem to be aware that instead of showing "a section of several square yards" they can be followed as definite bands for considerable distances. Even the smallest of them takes the form of a linear vein, and not of an included block.

Of true inclusions—that is, of blocks of older granite caught up and altered by the gabbro—there is not, so far as I have been able to discover, one single example to be found on the whole ridge including Druim an Eidhne. There must be dozens of veins and dykes, not merely within the "20 or 30 yards from the line of junction" where Prof. Judd observed them, and on the little portion of Druim an Eidhne where he has marked them on his map, but for some hundreds of yards across the ridge along its whole extent of a mile or more. In fact, the ridge is penetrated by many protrusions of the acid rock, and it is the ends and projections of these veins and dykes, visible at the surface, which Prof. Judd has mistaken for inclusions.

Let me describe two or three illustrative examples which will serve to show the various aspects of these apparently detached portions of the great acid intrusion. At the point where the footpath to Coruisk begins to ascend the rugged gabbro ridge, it is crossed by a small stream, and at this locality a well-marked vein of felsitic rock runs through the gabbro. If the observer turns northward from this point, up the craggy surface of Druim an Eidhne, he will, at a distance of about a hundred yards, come upon another vein, varying from 1 to 3 feet in breadth, traceable for 20 feet, and exhibiting the most perfect flow-structure, parallel to the walls, with rows of large, and sometimes hollow, spherulites. A few yards farther up the hill, another exposure (which may be a further portion of the same dyke) displays the relations represented in fig. 2 (p. 225). The portion of the dyke visible is about 18 feet long and 6 feet broad. The rock is a fine granular felsite or close-grained granophyre, with exquisite flow-structure, which not only keeps parallel to the boundary-walls, but follows all their irregularities of contour, its lines curving round projections and sweeping into eddy-like swirls, in such a manner as vividly to portray the motion of a viscous lava flowing in a cleft between two walls of solid rock.

[illegible]

[illegible]

[illegible]

the sake of the progress of geology I sincerely regret. Though doubtless much has still to be learnt regarding the behaviour of eruptive masses of igneous rocks, there are certain phenomena of which so many examples have been observed that they are generally considered to be well established. Among these phenomena are the felsitic, spherulitic, and flow-structures which are found in lavas and in the peripheral and apophysal portions of deep-seated bosses, at the margins of sills, and often in the body of dykes and veins. These structures have been so abundantly noticed under circumstances pointing to the effects of cooling and consolidation, that, though some of the details of the processes still need elucidation, the general conclusion has been accepted that the structures represent stages in the comparatively rapid chilling and solidification of molten material. The student who has mastered this part of tectonic geology, and who has become familiar with examples of these effects of cooling among rocks in the field, may well feel perplexed when Prof. Judd tells him that these very structures can be produced by re-fusion and such excessively slow cooling as must take place within a deep-seated basic eruption; and that blocks of granite, several yards in diameter, may in such a position be melted, and instead of assuming a distinctly crystalline structure, as it might have been supposed that, under these conditions of prolonged high temperature and extremely gradual refrigeration, they would have done, may acquire a fine felsitic texture, an exquisitely perfect spherulitic flow-structure, conforming to the surface of the enclosing material and presenting all the usual signs of true rhyolitic movement. His bewilderment will be still further increased when he learns from Prof. Judd that this alleged order of change is entirely borne out by microscopical investigation. He may surely be pardoned if he feels inclined to abandon in despair a subject wherein the testimony of field-evidence and of microscopic research may be made so entirely to contradict common experience.

Happily the conflict of testimony is not to be found in nature. I have shown, I think, conclusively that the whole of the phenomena in Skye are perfectly harmonious and intelligible, that they involve no exceptional occurrences, but that they exhibit in a singularly clear and striking manner the behaviour of an acid rock which has disrupted and invaded an older basic group. The literature of inclusions in igneous rocks cited by Prof. Judd, and his detailed account of the quartz-felsite fragments of Ascherhübel, though interesting in themselves, are really irrelevant to the facts observable at Druim an Eidhne and its neighbourhood. In the field he has missed the clear evidence of the dykes proceeding from the granophyre, and, following his original error, has reversed the true order of sequence of the volcanic rocks. With the microscope, the influence of the same unfortunate misreading has led him to invert the actual succession of structures.

The locality in Skye which he has now brought forward to prove his contention is only one of many which I have cited in support of the view that the acid protrusions are among the latest of the

whole series. Having demonstrated in the present paper how fully my reading of that locality was justified, I confidently appeal to the vast mass of evidence which is given in my memoir in the Transactions of the Royal Society of Edinburgh, as furnishing a body of proof sufficient to place this question finally among the well-established facts of British Geology.

EXPLANATION OF PLATES XIII. & XIV.

Plate XIII. Banded gabbro in the Tertiary volcanic series, ridge north of Druim an Eidhne, Glen Sligachan, Skye. (From a photograph.)

The portion of gabbro here represented is an abrupt face of rock about 7 feet long by 5 feet high. The darker bands show where the iron ores and ferro-magnesian constituents predominate; the paler layers consist mainly of plagioclase.

Plate XIV. Dyke of granophyre (6 to 10 feet broad) proceeding from the main mass and intersecting the banded gabbros. (From a photograph.)

The camera, in taking the original photograph, was placed on the main body of granophyre from which the marginal spherulitic and flow-structures can be traced up into the dyke. The dark mass to the left of the dyke is a portion of the banded gabbros lying between the dyke and the main mass of granophyre.

Discussion.

The President said that he had listened with much interest to the reading of Sir Archibald Geikie's paper; the Author had made out his case so clearly that no one, it might be supposed, could for a moment doubt that the interpretation which he had given was the correct and the only one; nevertheless, he had reason to believe that Prof. Judd had, with careful study, arrived at quite a different view of these same rocks. No one could doubt the abilities of these eminent geologists, and he must therefore conclude that the nature of the country was such as to render agreement very difficult, and the possibility of two observers arriving at quite different views, on the same ground, extremely easy.

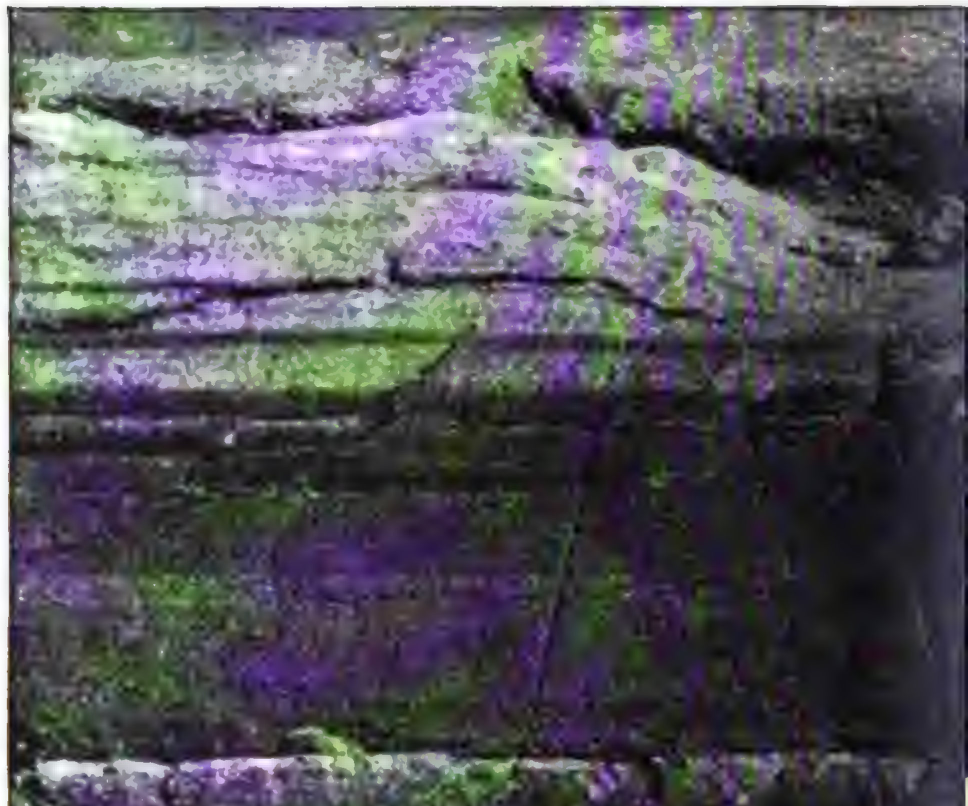
Prof. Judd remarked upon the circumstance that the Author's opening statement, though professing to be historical, entirely ignored the labours of John Macculloch and J. D. Forbes, who, from observations made at the very spot treated of in this paper, were first led to the conclusion that the gabbros of Skye are younger than the granites.

The speaker entirely agreed with the Author that the gabbro of the Cuillin Hills consists of a great number of sheet-like intrusions, sometimes showing the banded structure so common in the granulites. He had, indeed, gone much farther than this, and argued that these sheets are composed of the materials that had consolidated in the great ducts or fissures giving vent to the abundant currents of basaltic lava. He agreed, moreover, with the Author as to the great profusion of veins which traverse both classes of rock, and in his conclusion that these are really 'contemporaneous' or 'segregation-veins.' Nor did he dissent from the view that the granites frequently become fine-grained ('microgranitic' and 'felsitic') in the peripheral portions of their mass.

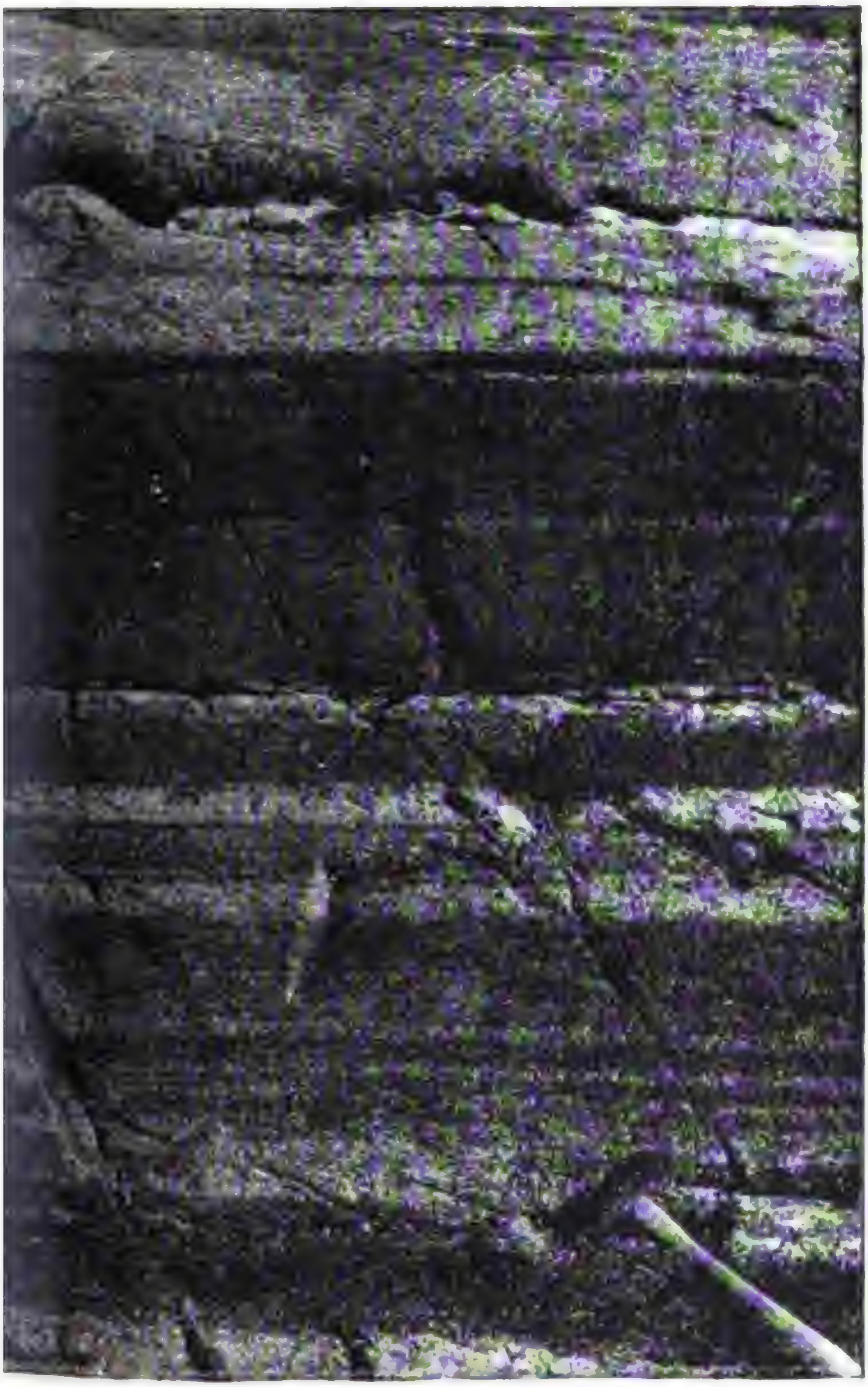
When the Author added that banded and spherulitic rhyolites are often found constituting the margins and apophyses of granitic bosses, he felt, however, unable to follow him: and the statement that it was such banded and spherulitic rhyolites which form the dykes, supposed to be apophyses of the granite, suggested to him grave reasons for doubting the interpretation of the phenomena put forward by the Author of the paper. The Author had pointed out the existence of a dyke-like mass of the banded and spherulitic rhyolite *in the very midst of the granite* of Meall Dearg, and he had admitted that this might possibly constitute *a later intrusion* than the granite itself. But if this were the case with the rhyolite in the midst of the granite, might it not also be equally true of the rhyolite in the peripheral portions of the same mass? The granting of this, however, would at once destroy the argument based on the statement that the granite itself sends offshoots into the gabbros. This was only one of several ways in which the appearances might be interpreted, without accepting the conclusions of the Author of the paper.

But while there was this uncertainty about the evidence of *veins*—and corresponding differences of opinion on the bearings of this class of evidence had been exhibited among competent observers, in the case of two previous discussions before the Society, the rival views being supported by a similar display of diagrams and photographs—there could be no doubt whatever as to the evidence of *included fragments*. The speaker exhibited hand-specimens taken from masses which were completely surrounded by the gabbro. The centres of these specimens consist of the normal micropegmatitic granite ('granophyre') of the district, the fused outer coating displaying all those phenomena which have been so well described by Lehmann, Bonney, Sauer, Bäckström, and other petrologists, as belonging to masses of acid rocks that have been caught up and enveloped in basic ones. In opposition to the Author of the paper, the speaker maintained that the demonstration of a single case of one rock being enclosed in another was proof positive as to their relative age. With respect to the specimens on which he relied, and the sections cut from them, he offered to submit his whole case to the three petrologists of the Geological Survey—in whose judgment and fairness he had the most perfect confidence.

The Author, in reply, remarked that Prof. Judd had left the essential part of the paper unanswered. It was beside the question to bring up the observations of earlier geologists. No amount of such testimony could avail in the teeth of plain facts. Prof. Judd had affirmed in his last paper that the presence of inclusions of granite in the gabbro was absolutely irreconcilable with the existence of veins of the same granite cutting the gabbro. But it must obviously be just as true that the presence of dykes of granite (or granophyre) cutting the gabbro is absolutely irreconcilable with the existence of inclusions of the same acid rock in the basic series. Prof. Judd had brought forward no evidence that his 'inclusions' were really such; but he (the Author) had adduced in



Banded Gabbro in Tertiary Volcanic Series, rid
(FROM A



north of Druim an Eidhne, Glen Sligachan, Skye.
OTOGRAPH.)

the present paper overwhelming evidence that the granophyre has disrupted the gabbros. Photographs were produced in which the light-coloured granophyre is seen to rise as a dyke through the dark gabbros and in which the same structures are displayed as occur along the margin of the main mass of granophyre and in the so-called 'inclusions.' Specimens were also exhibited showing that in the body of the granophyre, and in the dykes which could be traced diverging from it, the very same spherulitic and flow-structures occur which Prof. Judd describes as characteristic of his 'inclusions.' It had been shown in the paper that these 'inclusions,' instead of being irregular blocks, are really linear veins or dykes with flow-structure parallel to their walls and enclosing pieces of the surrounding gabbro. It had also been pointed out that the remarkable banded structure of the complex series of gabbros is truncated both by the main mass of granophyre and by the apophyses from it.

The Author had not criticized Prof. Judd's account of the microscopic structure of the material of his 'inclusions.' He was even willing to accept it as fairly accurate, with, however, the important reservation of the alleged proofs of re-fusion. But no amount of petrographical ingenuity could withstand the plain evidence in the field that the granophyre sends offshoots across the gabbros. In the face of this evidence it is mere waste of time and labour to dispute about points of minute detail.

17. *The* WALDENSIAN GNEISSES *and* THEIR PLACE *in the* COTTIAN SEQUENCE. By J. W. GREGORY, D.Sc., F.G.S., of the British Museum (Nat. Hist.). (Read February 7th, 1894.)

[PLATE XV.]

CONTENTS.

Note.—This paper was originally sent in to the Geological Society on October 19th, 1892, but owing to the writer's absence from England the reading, and consequently the publication, have been delayed. No reference is therefore made to some recent papers on this and an adjoining part of the Alps, as they do not affect the argument.

I. INTRODUCTION.

THE Cottian Alps consist of three main lines of mountains occupying an area roughly triangular in shape, and forming the extreme western segment of the great curve of the Western Alps. They may be divided into three groups: the Northern Cottians, running E.N.E. and W.S.W. from Roche Melon to Mont Thabor; the Western, running from Mont Thabor S.E. to Monte Viso; and the Eastern, which completes the triangle by continuing the line of the Graians southward from Roche Melon till it joins the Western chain at its southern end. Of these three ridges the Northern and the Western form the main topographic chain, which connects the group of the Graians with the chain of the Maritimes. The arrangement of these two divisions of the Cottians is, to a large extent, independent of their geological structure. Thus Mont Thabor is composed of Carboniferous and Triassic rocks; south-east of this we leave the Triassic limestones at Monte Chaberton and pass to the gabbros and variolitic series of Mont Genèvre, which are certainly not earlier than the Upper Mesozoic: to these succeed the calc-schists and mica-schists, and then a vast series of gabbros, serpentines, amphibolites (epidiorites, etc.), and glaucophane-schists, which extend from Bric Bouchet to the Viso. Along most of these Western Cottians the direction of the mountains does not agree with the strike of their constituent beds; branches from the main chain run off along a north-and-south line and show the efforts of the forces of elevation to adapt themselves to the rock-masses which they were upraising. Such, *e. g.*, is the range that forks from the main chain

to the north of the Col de Traversette and runs from Monte Granero through Punta Manzol and Punta Agugliassa to Punta Plengh. This explanation does not, however, apply to the north-and-south ridges that form the main features in what Mr. Coolidge aptly describes[1] as "the very tangled and little known ranges around Césanne."

A comparison of the Eastern with the Western and Northern Cottians reveals several points of much interest. Thus the two latter are simple topographically and complex geologically; they include rocks of very different ages and characters, from the Upper Mesozoic or Eocene diabases of Le Chenaillet and the Jurassic limestones of Monte Chaberton to the old eruptives of Monte Viso; they have been upraised by earth-movements of considerable complexity, involving extensive foldings, inversions, and overthrust faults. The Eastern chain, on the other hand, is complex and inconspicuous topographically, having been cut across by the valleys of the Waldenses; but it is comparatively simple geologically. It is composed essentially of a series of schists and schistose rocks—possibly bent into an anticlinal, with a series of banks of coarse fresh augen-gneiss occurring along the axis of the fold.

It has been generally agreed that the rocks of the Eastern Cottians may be grouped into three series, a fundamental Laurentian gneiss (the 'central gneiss' of Zaccagna[2]) at the base, covered by a double set of schists, the Upper and Lower Archæan schists of Prof. Bonney[3]; these three correspond to the 'gneiss antiche,' the 'zona delle pietre verdi,' and the 'terreni cristallini stratificati più recenti' of Gastaldi.[4] This classification and the view of the antiquity of the basal gneiss has been accepted by all recent writers on Cottian geology, including, in addition to those already quoted, Baretti,[5] Lory, Sterry Hunt,[6] Sacco,[7] and Gianotti[8]; by all, in fact, since the abandonment of the old view of the Jurassic age of the whole series. This classification, moreover, is in harmony with the almost universal sequence of the pre-Cambrian schists. M. Michel-Lévy has referred[9] to the identity in the threefold series in the Central

[1] W. A. B. Coolidge, Alpine Journ. vol. xiv. p. 336.

[2] D. Zaccagna, 'Sulla Geologia delle Alpi occidentali,' Boll. R. Com. geol. Ital. vol. xviii. (1887) pp. 346–417, pls. ix.–xi.

[3] T. G. Bonney, 'Notes on Two Traverses of the Crystalline Rocks of the Alps,' Quart. Journ. Geol. Soc. vol. xlv. (1889) pp. 67–109.

[4] B. Gastaldi, 'Studii geologici sulle Alpi occidentali,' pt. i. Mem. descriz. Carta geol. Italia, vol. i. (1871) pp. 1–48, pls. i.–vi.; pt. ii. *ibid.* vol. ii. (1874) pp. 1–61, pl. i.

[5] Baretti, 'Studii geologici sul gruppo del Gran Paradiso,' Atti R. Accad. Lincei, ser. 3, Mem. vol. i. pt. i. (1877) pp. 195–313, 7 pls.

[6] T. S. Hunt, 'Gastaldi on Italian Geology and the Crystalline Rocks,' Geol. Mag. 1887, pp. 531–540.

[7] F. Sacco, 'La Géo-Tectonique de la Haute Italie occidentale,' Mém. Soc. Belge Géol. Pal. Hydr. vol. iv. (1890) pp. 3–28, pl. i.

[8] G. Gianotti, 'Appunti geologici sulla Valle di Chialamberto (Valle di Lanzo—Alpi Graie),' Boll. Soc. geol. Ital. vol. x. (1891) pp. 149–167, pl. v.

[9] Michel-Lévy, 'Note sur la Formation gneissique du Morvan et Comparaison avec quelques autres régions de même nature,' Bull. Soc. géol. France, ser. 3, vol. vii. (1879) pp. 862–866.

Plateau of France, Britanny, and the Western Alps (Oisans), in Switzerland as at the Simplon, in Spain as in Cantal, in Germany as in the Eulengebirge and the Oberpfalzerwaldgebirge, and also in Canada. The same series, basal gneisses, then coarse gneissose mica-schists with amphibolites and upper less foliated schists and phyllites, can be followed even farther than M. Michel-Lévy has done; it occurs in China, as described by Richthofen,[1] and more recently by Vélain,[2] who has pointed out the close resemblance of the gneiss to that of the Simplon. In Brazil the same sequence occurs, on the authority of Hartt[3] and Sterry Hunt; in Tasmania, as described by Thureau[4]; in India[5] it is represented in the Sub-Himalaya by the central gneiss, the gneissose schists and foliated slate series, while in some places, as around Sikkim, the middle member of the 'Daling' series contains many hornblendic schists. In Scandinavia occurs the similar sequence of 'jern gneiss' (with magnetite), and 'gneiss gris à grenat,' or common gneiss with amphibolites, with overlying phyllites; in Finland the succession is the same, and Lucas[6] compares it with that established by Profs. Gümbel, Groth, and Bonney in Saxony, the Vosges, and the Alps respectively.

In all these localities the sequence is fundamentally the same, the only variation being in the position of the amphibolites, though these are always confined to the two upper divisions.

While the accepted theory of the structure of the Cottians numbered among its advocates practically all recent writers on the subject, and as it was in harmony with this almost world-wide sequence, it appeared rash in the extreme to doubt its truth. Two previous visits to the area and a study of its literature and maps had, however, raised several difficulties which appeared insuperable. If the gneiss were the oldest rock in the district, why had it escaped the crumpling and contortion, the foldings and faulting to which the other rocks have been so extensively subjected? Why are its minerals so fresh when those of the schists around are so weathered and altered? Why does it happen that the mica-schists near the gneiss are generally so much coarser than at a distance, and so frequently garnetiferous? Again, if the gneiss is the oldest rock, why have none of the intrusive sheets and dykes of serpentine and amphibolites of the 'pietre verdi' series ever penetrated it? They cut through all the other rocks, from the Mesozoic limestones to the

[1] F. von Richthofen, 'China,' vol. ii. (1882) p. 706.

[2] Vélain, 'Géologie de la Chine,' Bull. Soc. géol. France, ser. 3, vol. ix. (1881) pp. 474–475.

[3] C. F. Hartt, 'Geology and Physical Geography of Brazil,' 1870, pp. 550–551.

[4] Thureau, 'Tasmania—West Coast, Progress Reports of Mines, no. 2: Mount Heemskirk and its Mineral Deposits and Mines,' Tasmanian Parl. Papers, 1881, no. 82; and Johnston, 'Geology of Tasmania,' 1888, p. 23.

[5] Medlicott in 'Manual of Geology of India,' 1879, pt. ii. pp. 614, 616, 627.

[6] R. N. Lucas, 'Notes on the Older Rocks of Finland,' Geol. Mag. 1891, pp. 173, 174; see also Sederholm, 'Studien über archäischer Eruptivgesteine aus dem sudwestlichen Finnland,' Tscherm. Petr. u. Min. Mitth. vol. xii. (1891) pp. 98–100.

lowest mica-schists: they approach very close to the gneiss, but never enter it. Gastaldi's map [1] of the Paradiso, on the contrary, actually shows one broken across by the gneiss (fig. 2, p. 240). In reply to the enquiry as to whether any case were known of an intrusion of the 'pietre verdi' series into the central gneiss, Prof. Sacco assured me that such is impossible, as the occurrence of one of this series in the gneiss would prove that this belongs to the newer gneisses. Gastaldi, who fully recognized both the fact and its significance, boldly claimed [2] that this proved that the 'pietre verdi' rocks were not igneous but bedded sediments: if they were intrusive, he argued, they would certainly have somewhere cut the basal gneiss. There seemed, however, another alternative, viz. that the central gneiss may be newer and not older than the overlying schists; Gastaldi does not appear to have considered this explanation, which was not opposed to any of the facts known to me. Prof. A. C. Lawson's remarkable work on the geology of Rainy Lake,[3] proving that the 'Laurentian' gneiss was there intrusive into the overlying rocks which have been correlated with the Huronian, showed the possibility of the truth of this explanation. Prof. Lehmann [4] and Dr. Danzig's [5] confirmation of Naumann's view of the intrusive nature and post-Archæan age of the Saxon gneisses and granulites, and Mr. Barrow's [6] description of intrusive gneiss-dykes in Forfar, suggested the possibility that the intrusive nature of the gneiss might not be exceptional. Moreover, M. Michel-Lévy's [7] demonstration that the protogine gneiss which forms the nucleus of Mont Blanc is an eruptive granite, and not a basal gneiss, showed that the same relation holds in at least one place in the Alps. There are, however, considerable differences between the protogine gneiss of Mont Blanc and the fresh gneisses of the Cottians, and as these mountain-groups belong to different Alpine zones, which are arranged on very different plans, I was not inclined hastily to apply conclusions from one to the other.

Impressed by these doubts, I was led to devote most of the time at my disposal for field-work during the summer of 1892 to a careful examination of the Cottian gneisses, in the hope that by working along the junctions some sections might be found that would settle the exact relations of the two series. At the same time it became necessary to settle the nature of the relation between the schists and

[1] Gastaldi, Mem. descriz. Carta geol. Italia, vol. i. (1871) pl. vi.

[2] Gastaldi, in letter to T. S. Hunt, Geol. Mag. 1887, p. 536.

[3] A. C. Lawson, 'Report on the Geology of the Rainy Lake Region,' Ann. Rep. Geol. Surv. Canada for 1887, pt. F, 182 pp. and map.

[4] J. Lehmann, 'Die Entstehung der altkrystallinischen Schiefergesteine, mit besonderer Bezugnahme auf das sächsische Granulitgebirge....,' Bonn, 2 vols., 1884.

[5] E. Danzig, 'Ueber die eruptive Natur gewisser Gneisse sowie des Granulits im sächsischen Mittelgebirge," Mitth. Min. Instit. Univ. Kiel, vol. i. (1888) pp. 33-79.

[6] G. Barrow, 'On certain [Highland] Gneisses,' Geol. Mag. 1892, pp. 64-65; [see also Quart. Journ. Geol. Soc. vol. xlix. (1893) pp. 330-356.]

[7] Michel-Lévy, 'Étude sur les roches cristallines et éruptives des environs du Mont-Blanc,' Bull. Serv. Carte géol. France, no. ix. 1890, 26 pp. and plates.

sediments of Gastaldi's 'pietre verdi' group. This subject will be dealt with in a subsequent communication by Mr. A. M. Davies, of the Royal College of Science, London, and myself. Mr. Davies gave me the great benefit of his assistance, as well as the pleasure of his company, during the examination of the gneiss. I must moreover express my thanks to Prof. Sacco for the opportunity of examining the rock-collections named by Sismonda at Turin; also to Dr. G. Gianotti, who guided us over the sections described by him on the south side of the Valle Grande at Chialamberto; to Signor Ing. Sommariva, to whom we are indebted for much information regarding, and the opportunity of a visit to, the Vonzo mines; and to Prof. Stevens, of Turin, whose kind help added much to the pleasure of a visit to the Valle Grande.

II. The Cottian Sequence and Previous Literature thereon.

Even before Fournet's 'Mémoire sur la Géologie de la partie des Alpes comprise entre le Valais et l'Oisans'[1] and Lory's monograph, 'Description géologique du Dauphiné,'[2] had given a comprehensive view of the main features of the structure of the Cottians, it had acquired a somewhat extensive literature, dating from the works of Faujas St. Fond (1781), Robilant (1786), Morozzo (1793), and de Saussure (1796). We owe to M. Kilian[3] a bibliography of the French side of the range, and to Prof. Baretti and Dr. Portis[4] a similar work for the Italian; they are brought up to 1891 and 1881 respectively. It is, however, here unnecessary to refer to the earlier literature as, with the exception of the *absolute* age of some of the schists and sediments, there has been a general agreement amongst recent writers as to the *relative* age of the whole series. Lory, it is true, regarded the 'schistes lustrés' of Cesana as Triassic, a view recently put forward again on palæontological grounds, but he fully accepted them as younger than the underlying schists and both as newer than the gneiss.

The question of the relations of the gneisses and the schists has been twice discussed in recent years, and it is only necessary to refer to those two memoirs. In 1887 Zaccagna published his well-known paper 'Sulla Geologia delle Alpi occidentali,'[5] in which he described in detail five sections across the Western Alps from Mont Blanc to east of the Col di Tenda. He recognized the following sequence:—

[1] Fournet, Ann. Soc. roy. Agric. Lyon, ser. 1, vol. iv. (1841) pp. 105-183, 483-560; vol. ix. (1846) pp. 1-112; ser. 2, vol. i. (1849) pp. 185-269, pl. i.

[2] Lory, Bull. Soc. Stat. Isère, ser. 2, vol. v. (1861) pp. 1-240, pl. i.; ser. 2, vol. vi. (1861) pp. 1-260, pls. ii., iii.; ser. 2, vol. vii. (1864) pp. 4-252, map.

[3] Kilian, "Notes bibliographiques pour servir à l'histoire géologique des Alpes françaises—Le Dauphiné," nos. 1500-1566, An 26-27, 1890-91.

[4] 'Bibliographie géologique et paléontologique de l'Italie,' 2ème Congrès Géol. Internat. Bologna, 1881, pp. 3-36.

[5] Zaccagna, Boll. R. Com. geol. Italia, vol. xviii. (1887) pp. 346-417, pls. ix.-xi.

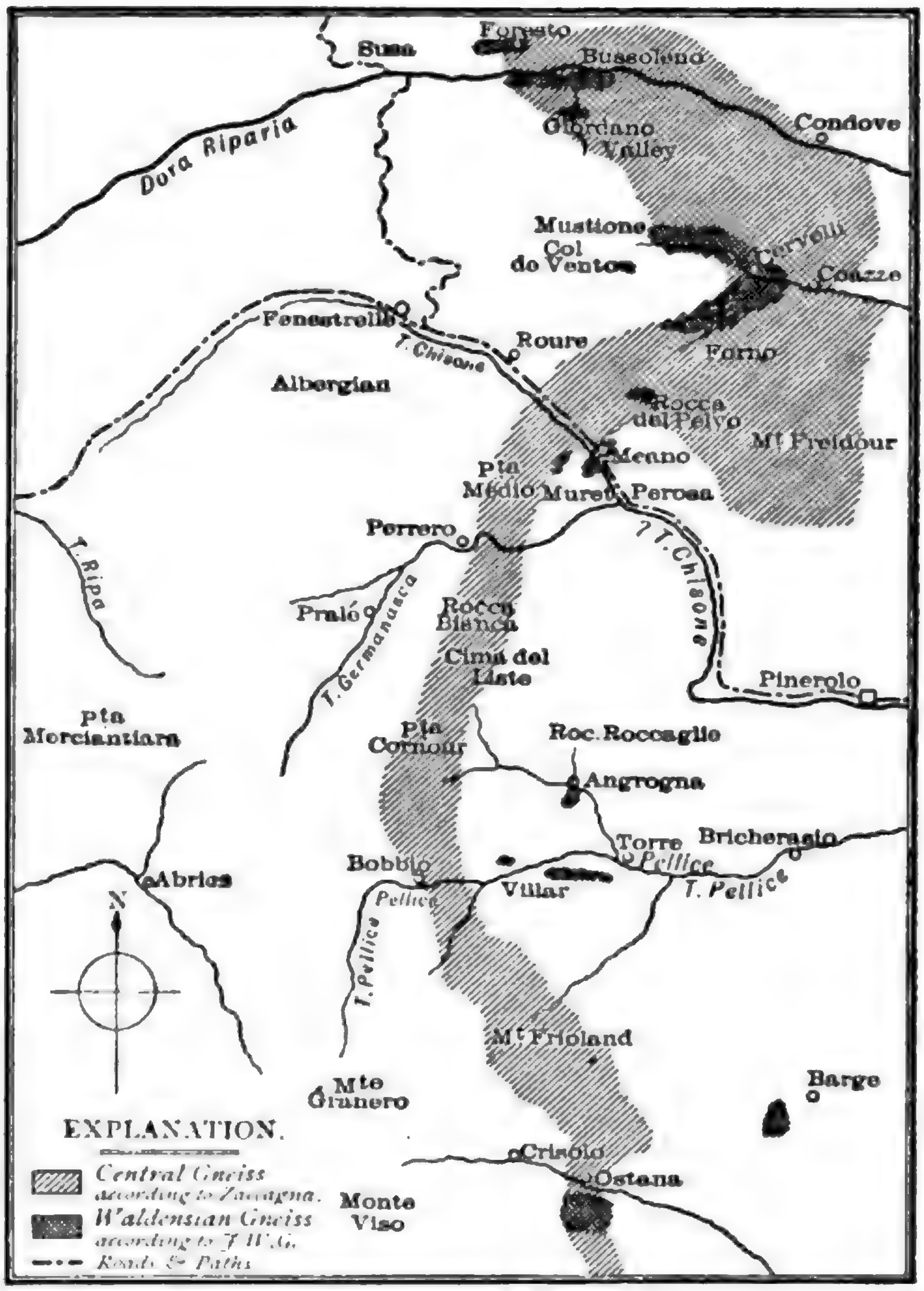
Miocene.		
Eocene.		
Cretaceous.		
Jurassic.		
Triassic.	Grey, schistose, compact, and brecciated limestones, talc-schists with serpentines, etc.	
Permian.		
Carboniferous.		
Pre-Palæozoic.	Zone of mica-schists, etc.	1. Calc-schists, mica-schists, quartzites, with saccharoidal limestones, tabular gneiss with syenites and granites. 2. Do. with serpentinous rocks, gabbros, diabase, and amphibolic, epidotic, and chloritic rocks. 3. Do. with massive diabase and porphyry.
	Zone of Central Gneiss.	Gneiss, augengneiss with white granite, talcose and micaceous granites (protogine of Mont Blanc).

With the Cainozoic and Mesozoic beds we have little to do; the important points are:—(1) that Zaccagna agrees with Gastaldi and some earlier writers that the whole of the true schists and the more normal sediments associated with them must be assigned to the pre-Palæozoic; (2) that he maintains that a definite sequence in them can always be established, and that the beds of 'central gneiss,' which Gastaldi and Baretti regarded as accidentally distributed through the schists, occupy a constant position at the base of the series. In his map he represents the 'central gneiss' as forming a continuous band from Bussoleno to Venasca, and in his section across the Southern Cottians shows it as occupying the axis of a great anticlinal. In his summary of conclusions he is very emphatic that "the central gneisses are not a mere lithological accident in the mass of mica-schists and other crystalline rocks, ... but they hold a constant place in the series and form the base and the nucleus of the various ellipsoids of elevation." Further, he maintains (pp. 415, 416) that "there does not exist a gradual passage between the crystalline rocks of the Alps and those of the fossiliferous series, as we ought to admit if we adopt the opinion of Lory, according to whom the Archæan calc-schists of the Cottian Alps and of the valley of the Arc represent a great part of the Triassic series."

In complete accord with the views of Zaccagna upon these main points are those of Prof. Bonney, who in 1889 [1] published his 'Notes on Two Traverses of the Crystalline Rocks of the Alps.' Bonney's two most important conclusions were the fundamental unity of the sequence of gneisses and schists in the Eastern and the Western Alps and their Archæan age. He crossed the Cottians to the north of Zaccagna's main section and concludes "that, broadly speaking, a stratigraphical succession can be detected in the gneisses and schists of the Alps, and that these rocks are of Archæan age." He strongly opposed Lory's view of the Triassic age of the 'schistes lustrés,' or calc-schists of Cesana, and attributed them to his Upper Archæan

[1] Quart. Journ. Geol. Soc. vol. xlv. pp. 67-109.

Fig. 1.—*Sketch-map illustrating the distribution of the Waldensian Gneisses.*



Scale: $\frac{1}{500,000}$ = ·1267 inch to the mile.

[For 'Crisolo' read 'Crissolo'; for 'Merciantiara' read 'Merciantaira'; for 'Giordano' read 'Giordani.']

series. In regard to the gneiss, however, Prof. Bonney twice suggested,[1] from microscopical examination, that it is "not impossibly of igneous origin;" but he insisted on the remarkable coincidence between it and the Laurentian gneisses.[2]

Dr. Diener, in the admirable summary of the subject in his 'Gebirgsbau der Westalpen,' accepts (pp. 15, 16) the same threefold sequence; but he remarks (p. 33) that the evidence for Zaccagna's anticlinal is not conclusive, and shows that part of the 'schistes lustrés,' though in another district, are certainly Triassic.[3]

The work of both Zaccagna and Bonney was executed on the passes; failure, however, on previous occasions to obtain sufficiently satisfactory exposures on the closely cultivated, moraine-strewn flanks of the valleys, led me to trust mainly to the peaks and ridges and to follow the strike from north to south, in the hope of thus finding a series of clear exposures of the junctions.

III. The Gneisses.

Zaccagna, in the exquisite map attached to his memoir 'Sulla Geologia delle Alpi occidentali,' figures the gneiss as a continuous band from Bussoleno to Venasca, a distance of some 80 kilometres or 50 miles. I had, therefore, planned to start at the north end, work steadily south along the western margin of the gneiss, and return north along the eastern margin. The first day's work, however, showed that no such simple scheme as this was practicable. The gneiss may be found a short distance south of Bussoleno, forming a low bank, ranging along the base of the hills, below the villages of Fornielli and Combe; but on attempting to work south along the line of junction marked by Zaccagna, one soon left the gneiss and struck a wide stretch of mica-schists, with calc-schists on the north-western border. At two or three places to the south there are small exposures of dykes or banks of the gneiss, but we could find no trace of the great sheet of gneiss which Zaccagna's map had led us to expect. All along the line, the results were much the same; instead of the continuous band of gneiss, there appears to be really a series of disconnected masses. This is the case not only in the Bussoleno district, but as far south as the line of gneisses was followed: it is shown in the map of Vasseur and Carez, which in this respect appears to be more accurate than Zaccagna and Mattirolo's map. It seems, therefore, best to discontinue the use of the term 'central gneiss,' which has been applied in the area to many different rocks and moreover assumes the point in dispute. But as the gneisses are mainly exposed in the Waldensian valleys they may be appropriately called the 'Waldensian gneisses.' They may be divided into seven groups, each of which is perhaps best described separately:—

[1] Quart. Journ. Geol. Soc. vol. xlv. (1889) pp. 83 and 99.

[2] *Ibid.* p. 97.

[3] Such is the case around Lago Paroird and Mont Brisé, 'Gebirgsbau der Westalpen,' p. 103.

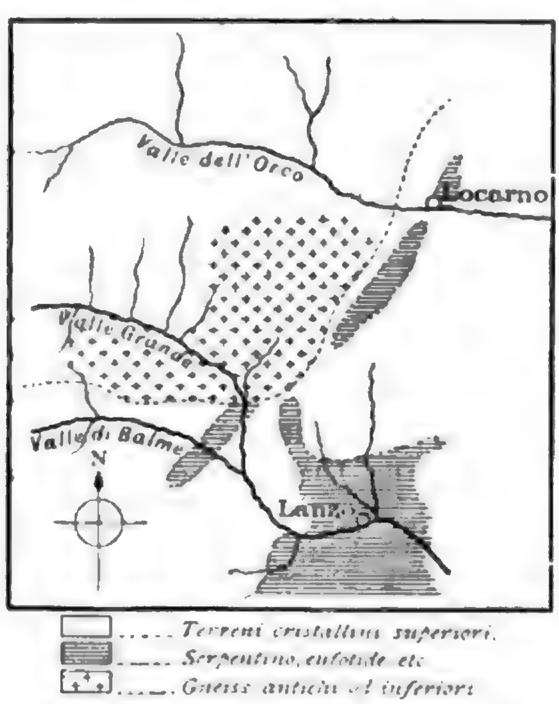
1. Bussoleno-Susa. (Dora Valley.)
2. Palé. (Sangonetto Valley.)
3. Meano. (Chisone Valley.)
4. Angrogna Valley.
5. Pellice Valley.
6. Barge. (Giandolo Valley.)
7. Crissolo. (Po Valley.)

Before, however, considering these, a digression to the exposure of gneiss nearest the northern end of the Cottians may well be made, in order to compare the rocks of the little-known Waldensian valleys with those of the classical massif of the Paradiso.

(*a*) The Paradiso Massif.

The Gran Paradiso has long been taken by geologists as the type of an Alpine massif in its simplest form, while it has been rendered classic by the descriptions of Desor, Gastaldi, and especially by the well-known monograph of Baretti.[1] The Paradiso belongs to the Graian Alps, but it is a member of the same Alpine zone as the Waldensian gneisses. It occurs immediately at the northern end of the Cottians, and consists of a series of gneisses and schists which,

Fig. 2.—*Reproduction of part of Gastaldi's map of the Paradiso.*



Scale: $\frac{1}{500,000}$ = ·1267 inch to the mile.

[For 'Locarno' read 'Locana.']

on the ground of lithological resemblance, have been correlated by Gastaldi and Baretti with the similar rocks farther south. The geology of the district has been fully described by Baretti, whilst in

[1] 'Studii geologici sul gruppo del Gran Paradiso,' Atti R. Accad. Lincei, ser. 3, Mem. vol. i. pt. i. (1877) pp. 195–313, pls. i.–vii.

1892 Dr. Gianotti[1] and Prof. Chelussi[2] have added considerably to our knowledge of the south-eastern corner of the massif. From the works of these authors we know that the main part of the massif consists of a coarse augen-gneiss which passes into a granite at the centre and becomes finer grained around the margin; it is surrounded by schists, which are often intensely contorted and penetrated by a series of gabbros and 'pietre verdi.' Near the gneiss the strike both of the schists and greenstones is as a rule parallel to the margin; and the maps show the beds of 'pietre verdi' and limestone in the schists encircling the gneiss, in a manner which suggests that their strike is due to uplift around a central intrusion. Gastaldi admits that the ellipsoid of elevation of the Paradiso is due to the intrusion of the gneiss, but he maintains that this was in a solid state,[3] and this is apparently accepted by most Italian geologists. Gastaldi, however, in the map previously quoted, of which part is here reproduced (see fig. 2), has shown one band of the 'pietre verdi' completely broken across by the gneiss in a manner that appears almost inexplicable for a solid intrusion. Though not inclined to place much reliance on Gastaldi's mapping, I thought it advisable to select this area for the examination of the relations of the gneisses and schists. A further advantage offered by this part of the massif was that the line of junction of the two had recently been precisely marked on a map to the scale of 1 : 25,000, issued by Dr. Gianotti in illustration of his paper on the mode of formation of the valleys around Chialamberto.

The central gneiss has been so well described macroscopically by Baretti[4] and microscopically by Chelussi[5] that there is no need here to say more than that around the margin it is typically a coarse augen-gneiss with felspar 'eyes' often 2 inches in diameter, and with all the minerals remarkably fresh.

In the centre of the massif the gneiss, as we are told by Baretti[6] and Gianotti,[7] passes into a normal coarse-grained granite, without any trace of foliation. At the actual contact with the surrounding schists the gneiss becomes much more finely foliated and the large felspar 'eyes' disappear. The junction, however, is unfortunately generally covered by moraine, and actual contact is rarely to be seen. Above the level upland valley, on the lower edge of which stands the hamlet of Vonzo, the stream of the same name runs for some distance along the line marked on Dr. Gianotti's map as the junction

[1] G. Gianotti, 'Appunti geologici sulla Valle di Chialamberto' (Valle di Lanzo—Alpi Graie), Boll. Soc. geol. Ital. vol. x. (1891) pp. 149–167.

[2] I. Chelussi, 'Studio microscopico di alcune roccie della Valle di Chialamberto in Piemonte,' pt. i. Giorn. Min. Crist. e Petrogr. vol. ii. (1891) pp. 196–210; pt. ii. *ibid.* pp. 270–277.

[3] Gastaldi, Mem. descriz. Carta geol. Italia, vol. ii. (1874) p. 58.

[4] Baretti, 'Gran Paradiso,' Atti R. Accad. Lincei, ser. 3, Mem. vol. i. pt. i. (1877) pp. 208–211.

[5] Chelussi, *op. supra cit.* pt. ii. Giorn. Min. Crist. e Petrogr. vol. ii. pp. 270, 271.

[6] Baretti, *loc. supra cit.*

[7] Gianotti, *op. supra cit.* p. 153.

of the two series; no exposure of this can be here seen *in situ*, but some of the boulders on the banks and in the bed of the stream do show the actual junction.

Fig. 3 shows one of these cases: the boulder consists of a mass of fine-grained gneiss including two masses of the 'pietre-verdi' series; the foliation of the gneiss flows round the inclusion, which shows clear contact-alteration to a depth varying between $\frac{1}{4}$ and $\frac{1}{2}$ inch. The gneiss is finer in grain than any we could find there *in situ*, but other boulders showed a passage from gneiss having characters identical with this to the normal coarse-grained rock. Microscopic examination completely demonstrates that the gneiss belongs to the central mass. Half an inch from the contact the gneiss is clear and colourless, and all the minerals are remarkably fresh; the main mass of the rock is formed by a water-clear quartz-felspar mosaic,

Fig. 3.—*Inclusion of 'pietre verdi' in the gneiss of the Vonzo Valley.*

[Reproduced from a photograph.]

the constituents of which are often united in pegmatitic intergrowths. The quartz has a well-marked circular polarization; the orthoclase is occasionally idiomorphic, and Carlsbad twins occur; these crystals also show signs of corrosion. Oligoclase occurs only as a few rounded grains. The mica is white and occurs in long blade-like crystals, most of which lie along the planes of foliation; a few, however, are scattered irregularly through the quartz-felspar mosaic.

Adding the letter Φ to indicate foliation, and the bracket ⌢ to show simultaneous crystallization, the formula for this rock, according to M. Michel-Lévy's system,[1] would be :

$$\Gamma\Phi\alpha\gamma\ \overline{F_{3,6}ma_1\overbrace{a_1q}}.$$

The rock is therefore a muscovite-granitoid gneiss.

Near the actual junction of the two rocks occur many flakes of chlorite which have doubtless been formed by the alteration of fragments of the 'pietre verdi'; a few corroded and broken garnets, showing optical anomalies due to strain, also occur. The contact-line is irregular, the gneiss having cut into the included block; this is now so altered that it is not easy to say what was its original constitution. The principal constituents are rounded grains of plagioclase, small, strongly dichroic crystals of green hornblende, and some irregular grains of glaucophane; these are scattered through a mass composed of rounded grains of epidote. A little zoisite and some patches of titanoferrite are also present.

The green included fragment is, therefore, an altered basic igneous rock and may be called a glaucophane-epidiorite.

Farther up the valley of the Vonzo the gneiss leaves the river and runs due north, below the chalets of Culet and west of the crag below the Capella della Madonna di Ciavinis. No section showing the junction could be found, but close to it the 'pietre-verdi' series is very contorted and along it loose blocks of garnetiferous amphibolite and glaucophane-schist are very abundant; these both probably indicate contact-alteration.

The junction of the two series is, however, much better shown on the south side of the Stura Valley, along a line to which we were guided by Dr. Gianotti; the sections occur on both sides of the steep Vallone Verso, north of the hamlet of Ortiero. In descending the valley for some distance below the main bridle-path one crosses the ordinary 'pietre verdi' series; the rocks of this series then become much contorted and garnetiferous, and 40 feet lower down pass into a crushed decomposed rock crowded with large garnets; immediately below this is a fine-grained gneiss-rock which Dr. Gianotti called a 'talcose gneiss' and accepts as the transition-rock between the gneiss and the schists. The talcose gneiss passes gradually below into the normal augen-gneiss. The actual junction here is clear, but it is not easy to be sure of its exact nature, as there has been a certain amount of slipping and squeezing out of the soft decomposed garnet-rock.

[1] 'Structures et Classification des Roches éruptives,' Paris, 1889, pp. 29–30, 37–38.

Γ = granitoid.	F_3 = apatite.	a_1 = orthoclase.
α = granitic.	F_6 = zircon.	q = quartz.
γ = pegmatoid.	m = white mica.	k = kyanite.
		e = epidote.

The brackets are used for extraneous materials caught up by a rock during its intrusion.

The talcose gneiss macroscopically resembles that in contact with the epidiorite in the Vonzo Valley, and subsequently described from Mustione and elsewhere in the Eastern Cottians. It appears to be a gneiss which has absorbed much basic matter from the schists; while the fact that the garnet-rock above it is crushed and decomposed is also a result of the contact-metamorphism.

On the opposite side of the Vallone Verso similar amphibolite-schists can be seen, on the edge of the platform on which stand the hamlets of Casa Girot and Casa Ortiero. Below them occurs a bed of quartzite which strikes towards the gneiss. The latter is well shown in a few small quarries; the uppermost of these is immediately below the quartzite, here altered to a quartz-schist. The gneiss is fine-grained, and in this condition it can be traced up to within 5 metres of the quartzite. In a second quarry, a little below the first, the gneiss is coarser and typically augen, characters which become more prominent as it is followed farther down the hillside.

The schists and the quartzite here dip 23° south-east with a strike of 32° south of west (magn.), whereas in the lower quarry and in numerous exposures farther down the cliff the foliation of the gneiss has a strike of 10° south of west (magn.). The gneiss below the quartz-schists contains none of the 'talcose' (or chloritic) material which occurs in it when in contact with the 'pietre verdi.'

The general conclusion to be drawn from these facts seems to be that the gneiss is here intrusive, as shown by the contact-metamorphism in the 'pietre-verdi' series, and the alteration of quartzites into quartz-schists: and also by the transgressive junction of the gneiss from its contact with the 'pietre verdi' to the quartzite.

The actual junction could not be clearly traced, as the hill-slope is here covered with brushwood, but in the absence of any evidence of a fault the strikes certainly favour an intrusive junction. On the north side of Chialamberto I had hoped for clearer evidence of this nature; but I failed to find the 'terreni cristallini superiori' that Gastaldi figures on either side of the band of 'serpentino, eufotide, ecc.' which his map shows in contact with the gneiss on the north-east of Chialamberto. Nevertheless, there is some evidence of a transgressive junction along the course of the stream at the base of Monte Bellavarda, opposite Madonna di Ciavinis. The foliation, as measured by Mr. Davies, runs 13° north of west, and along a line at an angle of about 75° with this (*i. e.* 62° south of west) a definite succession of the beds can be recognized; this includes ordinary amphibolite-schists, amphibolite with felspar-grains and nodules, and talcose amphibolite-schist. In this series, moreover, occur some masses of altered serpentine, the field-relations of which resemble that common to the peridotites of the Cottians. The rock consists of fairly large crystals of brown bastite, with very well-marked schillerization; the outlines are irregular and surrounded by an altered structureless zone, which still maintains its optical continuity with the central nucleus. These crystals are enclosed in a light-green serpentinous mass, crowded with needles and radial

clumps of tremolite. A few grains of olivine still remain. The rock was therefore originally a saxonite, though the rhombic pyroxene was probably hypersthene rather than enstatite. The mass occurs intruded in some chlorite-schists belonging to the 'pietre-verdi' series; its sudden western termination may be due either to its having been cut off by the gneiss or to the original peridotic segregation not having extended far in that direction.

We were glad to find that Signor Ing. Sommariva, of the Vonzo mine, had arrived at the same conclusions—as to the intrusive nature of the gneiss—as we had; the mine lies near the contact of the two rocks in a synclinal, which he believed to have been formed at the time of the gneissic intrusion.

(*b*) The Waldensian Gneisses.

1. *Bussoleno—Susa.*—The town of Bussoleno is situated on both banks of the Dora Riparia in the midst of a wide tract of moraine and alluvium, which here separates the Grand' Uja and Punta Lunel continuation of the Northern Cottians from the northern end of the eastern range. The mountains on both sides of the valley are mainly formed of mica-schists: but an extension of the calc-mica-schists of Cesana runs along the base of the south side of the valley as far east as the gorge of the Giordani, south-west of Bussoleno. From this point a low bank of gneiss forms the foot of the hill-slopes for some distance towards the east, and is extensively quarried below the villages of Combe, Fornielli, and Meitre. A similar rock, no doubt an extension of the same mass, occupies a corresponding position on the north side of the valley extending from Foresto di Susa to Grange. These are the northern exposures of the Waldensian gneiss, and Zaccagna has figured them as spreading over a wide extent of ground south and south-east of Bussoleno,[1] and thence extending in one unbroken line as far south as Venasca. It was therefore natural to strike from Bussoleno towards the south-west, to the line marked by Zaccagna as the junction of the gneiss and the schists.

One soon found, however, that it was not possible to apply that geologist's map too literally, and that a large extent of his 'central gneiss' is really occupied by mica-schists, calc-schists, and even 'pietre verdi.' Thus the foot of the hill-slopes at Capella Santa Parnella, about 1 kilometre south-west of Bussoleno, is formed of calc-mica-schists, in places garnetiferous; the foliation of the schists here dips 45° to the north-east, and strikes north-west and south-east. Higher up the slopes the calc-schist is succeeded

[1] There is a slight discrepancy here between the lettering and colouring of Zaccagna's map. According to the former, the gneiss extends as far west as Chiomonte, and it forms the whole of the basins of the Giordani and of the lower part of the Scaglione; the colouring, however, marks the western termination of the gneiss about 1 kilometre to the east side of the Scaglione, the course of which is thus wholly on the schists; the colouring is no doubt the more correct.

by a great thickness of brownish mica-schists, which can be seen in numerous crags around Combe, Fornielli, Tignaj, and Meitre; thence they can be followed along the hills southward to Giordani, and up the Gerrardo Valley. We found them from Giordani all along the line of a traverse across country past Pinetti, Cervelli, Condé, Travers à Mont, and Pois to Mustione.

Fig. 4.—*Sketch-map showing the distribution of the Waldensian Gneisses in the Bussoleno district.*

Scale: $\frac{1}{100,000}$ = ·6336 inch to the mile.

[For 'Gerrande' read 'Gerrardo'; for 'calc-schist' read 'calc-schist.']

The 'central gneiss,' on the other hand, appears to have a very restricted distribution, being limited to the bank stretching from below Fornielli past San Basilio to below Meitre. The foliation of the gneiss here strikes about due east-and-west, with a dip of 75° north. A second bed occurs intercalated in the schists east of Giordani: it can be seen on the right bank of a stream just above the village. Better exposures are seen as a line of low crags, above the road from Giordani to Fornielli: at the foot of this the path turns to Tignaj, which leaves the main road just north of Giordani.

One kilometre south of this another gneiss-bed crops out on the right bank of the Gerrardo Valley, opposite where R. is marked on the map. It occurs here as a bed, some 25 feet wide, which appears to be a dyke: the junction with the surrounding gneissoid mica-schist is irregular: the only evidence of contact-metamorphism which we noticed is that the adjoining gneiss is garnetiferous.

These three gneisses appear so strikingly similar in their lithological characters that in all probability they are part of the same original rock.

The gneiss at the quarries below Meitre, when examined microscopically, is seen to consist in the main of a water-clear quartz-felspar mosaic, which forms large white 'eyes,' around which curve lines of long blade-like crystals of white mica. The quartz shows well-marked undulatory extinction; it is often pegmatitically associated with the felspar. Apatite and zircons both occur in the mosaic. The felspar is sometimes idiomorphic, and crystals of it are seen completely enclosed in quartz.

The formula for the rock is therefore:

$$\Gamma\Phi a\gamma\ \mathrm{F}_{5\,6}\overline{\ a_1}\ m\,\underline{\widehat{a_1}q},$$

and the rock is a muscovite-gneiss.

The dyke in the Gerrardo Valley agrees with this in the main. The principal differences are the small proportion of orthoclase, many of the crystals of which show a zonal regrowth. Moreover the micas are in thicker crystals, and there are a good many eroded crystals of kyanite; a few grains of the last-named mineral occur in the Bussoleno gneiss.

The formula is therefore:

$$\Gamma\Phi a\gamma\ \overline{\mathrm{F}_{5\,6}}(k)\overline{a_1}\ \underline{m\widehat{a_1}q},$$

and the rock may be regarded as an aplite.

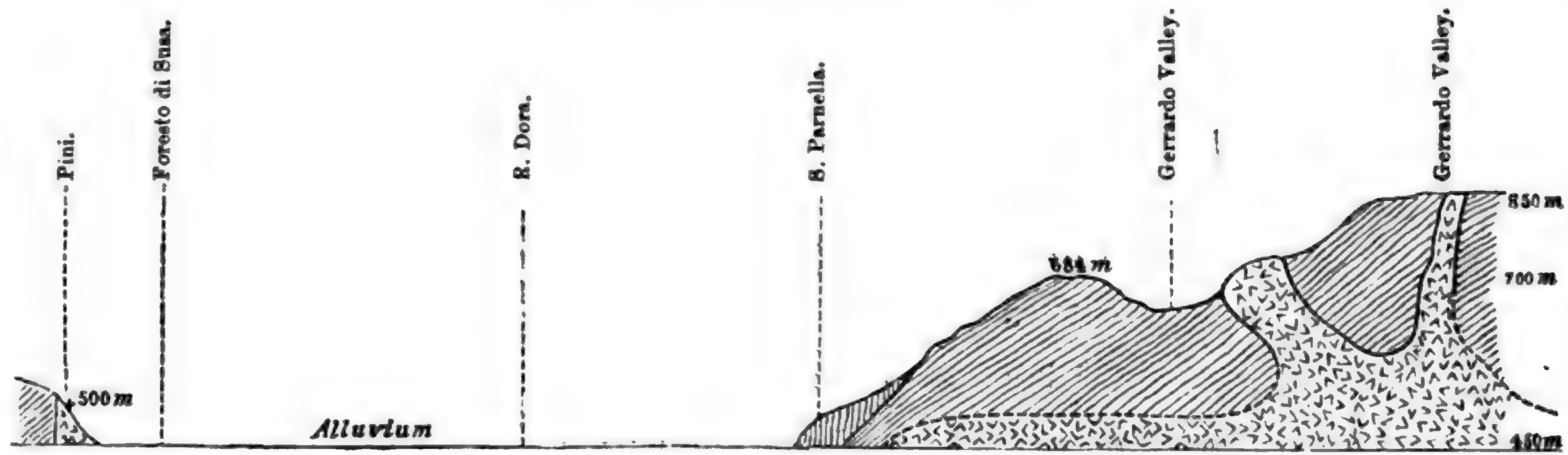
We were unfortunate in not finding in this district any very clear sections showing the junction of the main mass of the gneiss and the schists; but around Fornielli there appears to be a gradual passage from the normal gneiss to one rendered coarsely 'augen' by numerous inclusions of quartz-nodules. At the upper end of Fornielli, in a chestnut grove on the south side of the main road, there is an exposure of white gneiss with similar quartz-nodules and impregnated with calcareous matter. Close to this the mica-schists are seen *in situ*; they are crowded with garnets near the junction, while the adjoining schists are strongly contorted.

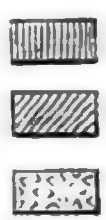
Though it is not possible to prove the actual connexion of the three gneisses, it seems highly probable that they are part of the same massif; the section on the following page (fig. 5) shows their field-relations upon this view. The three rocks agree very closely in composition, as is shown by their formulæ, and in the freshness of their minerals in contrast to those of the rotten, decomposed rocks in which they are intercalated; the only differences between them are just those which might be expected between an intruded mass and its apophyses. In this case the Susa and Fornielli exposures represent the massif exposed by the erosion of the Dora Valley.

2. *Palé.*—Between the gneiss-dyke in the Gerrardo Valley and the next exposure seen at the Col de Vento, the rocks along the line traversed were wholly of the gneissoid mica-schist; these occur along a line from Pinetti, Cervelli, Condé, Travers à Mont, Pois, round the flanks of Punta Rossa and south along the Rio di Gravis to Mustione and the Col de Vento. South and west of this line

Fig. 5.—*Section from Foresto di Susa, across the crag W. of Combe & across & up the Gerrardo Valley.*

(Length about 4 kilometres = $2\frac{1}{2}$ miles.)



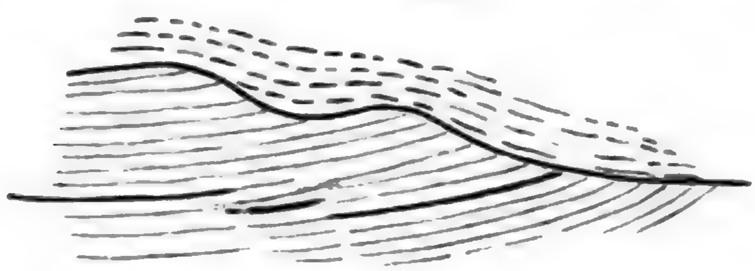


Note.—The Waldensian Gneiss does not here crop out on the south bank of the Dora alluvium, as it does $\frac{3}{4}$ kilometre to the E.

there appears to be a great extension of the upper schists with 'pietre verdi,' with gabbros, serpentine, amphibolites, and variolites. The true Col de Vento is on the mica-schists, but immediately south of it is a dyke of gneiss intrusive into the 'pietre verdi' series; a narrow and not very easy gully leads to a small col which crosses the ridge at a height of 2290 metres. This runs along the junction, the gneiss forming the north wall and the serpentine the south. The serpentine[1] is greatly schistified and contorted, while the gneiss has a somewhat greenish colour, doubtless due to the absorption of the neighbouring material. At the upper end the gully forks, and in the northern branch the gneiss can be seen in contact with a much altered limestone belonging to the schist series. The gneiss between the two branches of the gully is much decomposed. Close by the summit of the right-hand branch the gneiss crosses the gully and forms the south wall, and the rock is there still fresh.

Between the top of this gully and the Col de Vento is a band of limestone which is cut into by the gneiss, and the junction is well shown on the south wall of the northern fork of the gully. The

Fig. 6.—*Junction of gneiss and limestone in a gully north of Col de Vento.*



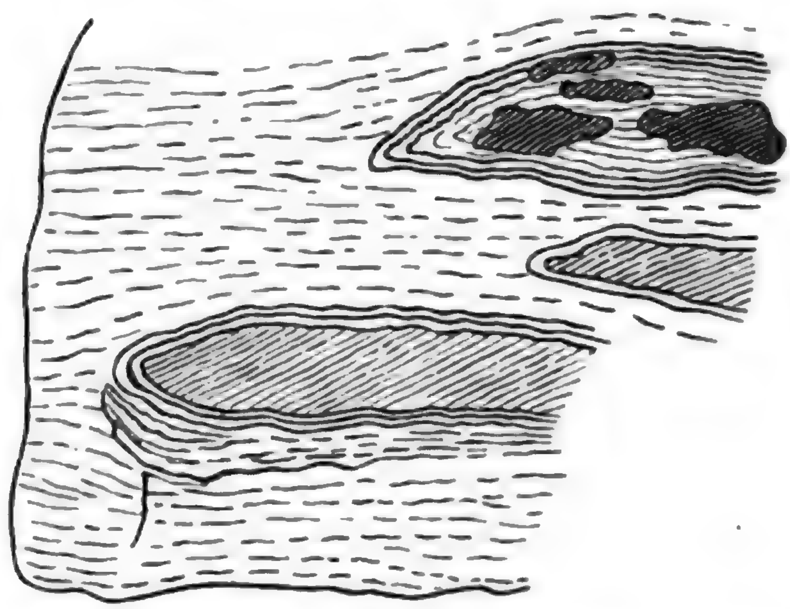
accompanying figure shows the actual junction and the way in which the limestone-bedding ends off against the intrusive gneiss. The limestone is altered at the contact: the microscope shows it to consist of a clear twinned calcite, some small rounded masses of untwinned calcite, and numerous small crystals of dolomite. These are all included in what appears to be a crushed calcareous groundmass; in this some authigenous blade-like crystals of white mica are further evidence of alteration.

In connexion with the Col de Vento gneiss-dyke it is necessary to consider a boulder which occurs beside the path a little below Mustione, of which a sketch is reproduced in fig. 7, p. 250. This shows two fragments of the 'pietre verdi' series included in gneiss; both inclusions are distinctly altered on the margin, the larger to a depth of 1 inch, and the smaller to $\frac{4}{5}$ inch. The gneiss belongs to the

[1] 'Serpentine' is here used as a general term for any altered peridotite. This rock was probably a lherzolite, as the microscope shows the presence of both rhombic and monoclinic pyroxenes, and of a little oligoclase; these are included in a light-green serpentine groundmass containing many needles and prisms of tremolite; some of the latter are sufficiently large to show the hornblende cleavages.

type of talcose gneisses, and is of a faint green colour; this no doubt it has acquired from the absorption of some of the 'pietre verdi.' The microscope shows it to consist of the usual pegmatitic quartz-felspar mosaic with bands of white mica; the dark colour of hand-specimens is seen to be due to inclusions of an indeterminate opaque material, which appears reddish-brown by reflected light. A series of broken and corroded garnets, often showing double refraction, also represents material collected from the surrounding schists. The foliation of the gneiss flows round the included fragments, like a true fluxion-structure. Though we did not find similar inclusions *in situ* at the Col, the exact resemblance of the gneisses leaves little doubt that it was derived from the dyke which we examined, or from a similar one.

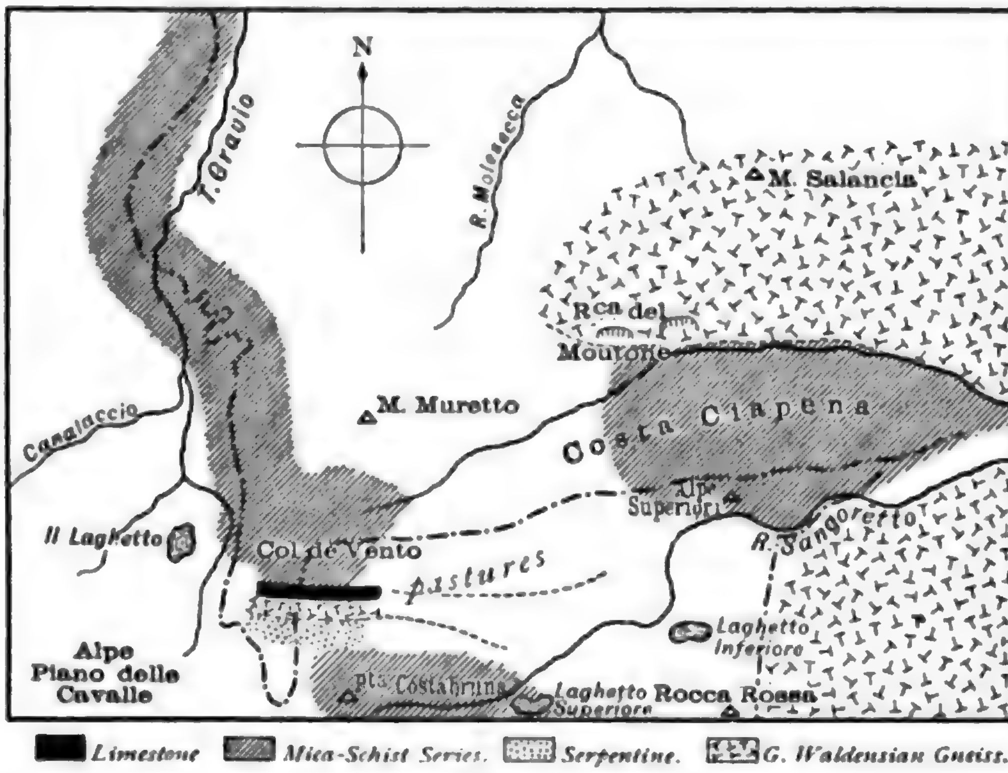
Fig. 7.—*Gneiss, with included fragments of the 'pietre verdi' series at Mustione.*



South of the gneiss, along the northern arête of Punta Costabruna, the serpentinous schists (probably an altered lherzolite) rise into a sharp crag; south of this, the mica-schists recur again, and these form the summit. On the eastern side of the pass and ridge a long gradual slope of meadow-land extends down to the Sangonetto Valley, and consequently there are no exposures. The gneiss, however, occurs extensively developed on both sides of this valley; on the north it forms the ridge of Monte Salancia, from the crags of the Rocca del Moutone to Monte Luzera (the Punta Siudre of the $\frac{1}{100,000}$ map). On the south side it forms the northern arête of Rocca Rossa, see fig. 8, p. 251. The gneisses of the two sides of the valley are at first separated by the schists, a wedge of which appears to extend into the gneiss, as far as the 1500-metre contour, down the Poirent Valley (a tributary of the Sangonetto). East of this point, as far as Dirotto, all the exposures seen were of gneiss. Still farther down the valley widens, and, as we had no time to leave the road, we could see no rocks *in situ*.

Unfortunately lack of time prevented any attempt at a precise determination of the boundaries of the gneiss, even if such be possible; but it seems most probable that the dyke at the upper Col de Vento is an offshoot from the great mass of gneiss about Palé.

Fig. 8.—*Sketch-map of the gneiss exposures round Col de Vento.*



Scale : $\frac{1}{50,000}$ = 1·267 inch to the mile.

[For 'Sangoretto' read 'Sangonetto.']

3. *Meano, Perosa, and Chisone Valley.*—On Zaccagna's map the gneiss band is shown to cross the Chisone Valley between Meano and Roure; two unnamed streams are marked as traversing the gneiss, and these occupy the positions of the Borsetto on the south side of the Chisone and the Balma on the north. Meano is itself placed as on the extreme eastern margin of a granite which here separates the schists and the gneiss. Eastward from Meano to Pinerolo the whole valley of the Chisone is coloured as schist. There are, however, at S. Germano, large quarries of a pale coarse gneiss, which seems to be a typical 'central gneiss.' But in this part of the valley the chances of actual junctions are very remote; and, as Prof. Bonney has already described the rock and remarked on its possibly intrusive nature,[1] it did not seem necessary to stop to examine it.

After leaving Perosa Argentina the road rises gradually, and there are no exposures worth mentioning, though the hills on either side are clearly of mica-schist; 1½ kilometre distant, however, a quarry in the pale-coloured gneiss occurs on the northern side of the road.

[1] 'Two Traverses, etc.,' Quart. Journ. Geol. Soc. vol. xlv. (1889) p. 83.

The microscopic structure of the rock has been described by Prof. Bonney (*op. supra cit.* p. 104); the only addition that I would desire to make to this is in regard to the presence of the large number of dark segregations. These are often at least 4 inches wide and 12 to 16 inches long; the longest diameter of the fragments is always parallel to the foliation.

On the opposite side of the river the gneiss is much better seen in some larger quarries, while on the eastern margin of the mass a certain amount of evidence as to the junction is obtainable. The gneiss forms an irregular bank occupying the axis of an anticlinal; the schists on the east side dip 10° W.S.W., while in the cliff below the ruined castle of Brandonegna they dip 10° N.W. At the foot of the cliff the gneiss is fairly coarse, but when traced towards the junction it becomes finer, and it is not easy in the field to fix on the exact line of separation between the gneiss and the gneissoid mica-schists which overlie it. The microscope, however, leaves no doubt of the distinctions between the igneous and the clastic rocks.

The igneous gneiss near the junction is finer-grained than that seen in the quarry on the opposite side of the river; it differs from the gneisses that have been previously described from Bussoleno and the Gerrardo Valley by the presence of a good deal of biotite in addition to the white mica. Epidote in small rounded grains is also abundant. This and the micas are included in a groundmass of a water-clear quartz-felspar mosaic, which was the last constituent to solidify. The formula may thus be written:

$$\Gamma\Phi\alpha\gamma\ \mathrm{F}\overline{_{s\,s}(e)\mathrm{M}ma_1}\ \underline{\overbrace{a_1q}}\ ;$$

and so the rock is a typical Waldensian gneiss with some foreign inclusions.

An examination of one of the most gneissoid of the adjoining mica-schists shows several marked differences. The materials in this belong to two very different sets. There are some quartz and zoisite aggregates which doubtless represent broken-down plagioclase; they are included in an indeterminate granular material, which contains many small authigenous flakes of white mica. These represent the original constituents of the mica-schists, now completely metamorphosed by the intrusion of the second group of constituents. There are thin bands of fresh granulite, composed of quartz, orthoclase, and some white mica.

The formula for this rock is:

$$\Gamma\Phi\alpha\gamma\ (\overbrace{zq}\,x)\mathrm{F}\overline{_{s\,s}ma_1}\ \underline{\overbrace{a_1q}}.$$

It is probably due to the injection of the schists by gneissic materials, similar to those cases around the protogine intrusion of Mont Blanc which have been described by M. Michel-Lévy.

The brown schists recur to the west of this narrow band of gneiss, and before attaining Meano a cliff is passed in which they are

almost vertical, with an E.S.E. strike; a well-marked band of fault-breccia here indicates a fault. Thence westward no sections occur on the road until reaching La Balma, where, beside the mule-path at the west end of the village, there is a crag of the ordinary brown gneissoid mica-schist dipping 42° to 23° west of north. The same schists extend up the Balma Valley to halfway between the confluence of the Balma and the Forcho and the talc-mine at Roussa; then they recur above the mine, where an amphibolite occurs in them; they also form the lower slopes of the Rocca Rossa, and thence they can be followed to the south side of the Col Roussa, and southward to the summit of Monte Bocciarda. Near the Alpe di Bocciarda, however, banks of the central gneiss crop up from the pastures, and appear to extend east towards the Punta Sarasina and the Monte Uja. The actual junction here is hidden by pastures, and an attempt was therefore made to descend to the south in the hope of finding it exposed. The head of the Comba di Bocciarda is close to the junction, and a small galena-mine may mark the exact position; owing to the steepness of the descent, however, and a mist that prevented our following the junction, we saw nothing but gneissoid mica-schists, with some amphibolites, till we reached the 1300-metre contour. The Roc del Pelvo, which rises above the stream from the base of the great cliff down which we had scrambled, is a sharp pyramid of gneiss and affords clear evidence of intrusion. The foliation of the gneiss dips 45° N.N.E., while the strike is E. 27° S.; 20 yards from the junction with the gneiss the schists to the north are almost horizontal, but at the contact they are sharply bent upward and are much altered. The gneiss at the junction is impregnated with lines and fragments of dark-coloured included material. Microscopic examination shows that the rock is a normal Waldensian gneiss. It differs from that described from Bussoleno by the presence of much extraneous matter occurring as lines and rolled-out fragments. Most of the included material is indeterminable, but flakes of chlorite and some rolled, broken, and slightly doubly-refracting garnets may be recognized. The inclusions farther from the contact are rarer and more altered; they consist in the main of green and brown hornblende and numerous small garnets; there are numerous idiomorphic but corroded crystals of orthoclase in the gneiss. The adjoining schists present the same characters as that above the gneiss in the section south of the Chisone; the rocks consist of bands of chloritic and amphibolic material separated by thin seams of granulite.

A manganese vein which has been worked occurs along the junction of the gneiss and schists, on both sides of the valley. There are no slickensided surfaces or other evidence of a fault, and the whole aspect is that of an intrusive igneous mass. This is clearly demonstrated by the contortion and metamorphism of the adjoining schists, and the inclusions in the gneiss.

In regard to the possible existence of another bed of intrusive gneiss farther west, between Castel del Bosc and Roure, I am unable to express a definite opinion. Zaccagna and Mattirolo's map marks the

south-eastern limit of the gneiss as crossing the main valley at the confluence of the Balma and the Chisone; we went for some little distance beyond this point, and failed to find anything but the brown mica-schists. If the gneiss does, however, occur, it cannot be continuous with that of the Bocciarda and the Pelvo, or we should have seen it in our traverse to the north. Abundance of the gneiss, however, occurs on a talus slope to the south-west of Castel del Bosc, by the first fork after crossing the Chisone, along the bridle-path leading to the hamlet of Garner. Erratics of the same rock are found on the grass slopes west of the summit of Punta Medio Muret, and probably indicate its occurrence somewhere along the ridge between this peak and Punta Raccias; but a dense cloud prevented any search for the rock *in situ* at this point. With these exceptions the whole of the rocks crossed between Castel del Bosc and Perrero were of the schist series, with intrusive amphibolites and interbedded limestones and dolomites. The last are well seen in some crags on the south-eastern ridge of Punta Medio Muret, between the summit and the point marked 2004 metres; the dolomite is much contorted, and is associated with some mica-schists containing enormous garnets. The actual summit of Punta Medio Muret is made up of the gneissoid mica-schist which so often occurs in the neighbourhood of the intrusive gneisses. Between Castel del Bosc and Garner the schists have a prevalent east-and-west strike: but between Massello and Perrero the strike has worked round to W. 30° N.

Near Perrero occur several large beds of amphibolite, as at a crag above Maniglia and east of Quin, which is apparently intrusive along the strike. A similar rock, probably an epidiorite, is worked for road-metal at a quarry ½ kilometre east of Perrero. It occurs here in a position on which Zaccagna has marked 'central gneiss.' There did not seem to be any evidence of the existence of that rock at this point. There is a good exposure of mica-schist, richer in mica and paler in colour than is usual, at the sharp bend of the road about 1 kilometre from Perrero; here a foot-bridge crosses the Germanasca and a bridle-path leads south to Grangette and Poet Soprano, as far as which all the exposures noted were of the coarse gneissoid mica-schist. Above the latter, large garnets become abundant; farther up, where the path bends round the flank of Bocca del Cavalupo at a part where it runs level for some hundreds of yards, there is an amphibolite which is clearly intrusive into the gneissoid mica-schists. The path thence rises to the ridge between Rocca Bianca and Bocca del Cavalupo, which it crosses by a col at the height of about 2025 metres.

From this point we kept south along the main ridge as far as Punta Cornour. The whole line is marked by Zaccagna as 'central gneiss,' and it is therefore advisable briefly to refer to the main types of rocks which compose it. At the col between Rocca Bianca and the Bocca del Cavalupo, the rock is a pure white, massive, crystalline, saccharoidal limestone, which has been there quarried for the kilometre-posts on the new military road. The limestone is

inclined to the north, and is overlain by mica-schists which form the 2051-metre point north of the col; the band thence rises, and is succeeded by masses of dolomite intensely folded and contorted and with beds of 'pietre verdi,' probably of a clastic origin, caught in between the limestone masses. The beds here strike 35° N. of W., while the thrust has come from approximately W. by S. Along this ridge, in spite of the intense foldings of the rocks, there is little evidence of any definite schistosity, and the actual summit of Rocca Bianca (2379 metres) is of a rock with foliation so imperfect that in the field we called it a micaceous grit; judging, however, from the great extent to which the quartz-grains are seen to be corroded, when examined under the microscope, this rock is probably a quartz-porphyry. South of the Colletta Bianca the rocks become more schistose and belong to the 'pietre verdi' series with numerous quartz-veins. The summits of Cima del Liste and Punta Bruta, however, mark a return to a less foliated series, being formed of a micaceous grit or schist breaking into large flat slabs, with a general strike north and south, at one place working to 10° E. of N.; the dip is 13° west. Farther south the strike is 10° W. of N., with a westerly dip of 16°. Associated with these evenly-foliated schists there are, on the south face of Punta Bruta, some interstratified thin green beds which probably represent layers of volcanic ash. There are also numerous blocks of a green rock in the same schists; they range from about $1\frac{1}{2}$ to 3 feet in length, and in their present form are lenticular; the long axes are in the plane of foliation, the lines of which bend round the blocks. Microscopic examination shows them to consist of garnets, chlorite, tremolite, and epidote: they represent altered blocks of a basic igneous rock, and their association with what is possibly a bed of volcanic ash led us in the field to consider the possibility of their being ejected blocks. The microscopic evidence neither confirms nor conclusively disproves this hypothesis.

In many places along this ridge between the Bocca del Cavalupo and Punta Cornour the rocks are either not foliated, or the foliation, such as it is, is coincident with the bedding; this is probably the case also with the rock which includes the eclogite-blocks. In the 'roches moutonnées' around Lagho d'Envoi, a charming little lake in a glaciated rock-basin, we have clear evidence that such is not always the case, as the vein there has been intensely contorted, before the foliation of the rocks; the foliation here has the normal strike of 10° W. of N., with a westerly dip of 16°. Around the flanks of Capello d'Envoi the schists become coarser and the limestones are schistified.

Evidence for the same independence of the foliation and stratification is seen in the view of Punta Cornour from Tredici Laghi. A massive bank of white rock (probably dolomite) may be observed interstratified between masses of the 'pietre-verdi' series; the white rock dips to the west, but the foliation dips much more sharply and crosses the bedding at a high angle.

Near the summit of Punta Cornour, the large garnets and the

crushing of the schists indicate a region of greater disturbance than in the Cima del Liste area.

Boulders of the central augen-gneiss occur on the northern face of the Punta Cornour, and this, combined with other facts subsequently noted around Bobbio Pellice (5 kilometres south), led me to think that this is probably an outcrop of the gneiss to the south. Ill-health, however, prevented an examination of the ground in this direction.

4. *Angrogna Valley.*—We had thus crossed from Perrero to the highest point between the Germanasca and the Pellice valleys, keeping along the line coloured by Zaccagna and Mattirolo as 'central gneiss,' without seeing the slightest traces of this rock, except for the single boulder on the Punta Cornour. Limestones, dolomites, grits, and some quartz-porphyry rendered slightly schistose, were the main rocks met with. The north-and-south traverse was therefore discontinued, and we then descended the Angrogna Valley towards the east in the hope of finding on its flanks some further exposures of gneiss, which it was possible that Zaccagna might have accidentally represented too far west.

Nevertheless, from Passo Roussa as far east as Gaisset, the only rocks seen were schists with interstratified beds, of which some are apparently intrusive amphibolites and others clastic green rocks. At Gaisset, however, a mass of fine-grained and locally foliated gabbro crosses the valley and forms a massive hill on the north side of that chalet; before crossing the stream near Pra del Torno, a dyke of compact dark-green porphyrite crops out across the path. Below Pra del Torno the normal mica-schists recur, and they are at first garnetiferous. Farther from the gabbro massif the schists are finer and less crystalline, and opposite the bridge at the angle of a sharp bend of the river, nearly 1 kilometre S.S.W. of Pra del Torno, the schists are comparatively unaltered and anthracitic.

A little farther round the curve a sharp crag, Rocca Roccaglie, overhangs the path to the north, and this is cut through by dykes of white aplite; a much finer exposure occurs in some rocks which here interrupt the course of the stream.

The main rock is a member of the 'pietre-verdi' series; the commonest variety is a rock which is probably an altered andesite, cut through by a fine-grained gabbro dyke. Both rocks have been subsequently invaded by a complex of intrusive aplite-veins (see fig. 9, p. 257). The aplite or granulite-veins vary in width from a few inches to 4 feet; and the coarseness of the rock varies with the width of the dykes. Microscopic examination shows that the rock consists in the main of quartz-felspar mosaic, with some larger eroded crystals of orthoclase and a foliation determined by bands of white mica. Its formula, excluding accessory minerals and some foreign material absorbed from the surrounding rock, is:

$$\Gamma\Phi\alpha\gamma\ \overline{m}\,\overline{\alpha}\ \widetilde{\alpha q}$$

which is that of the typical gneiss of the district.

The evidence of this exposure is unquestionable. There can be no doubt of the intrusive character of the dykes, nor that these are composed of an acid rock in which all gradations can be traced from a compact aplite or granulite to a fairly coarse, well-foliated gneiss. It appears that the dykes are an offshoot from a large mass below, which has not been exposed; its existence can be inferred from the elevation of the overlying beds into an anticlinal, as is shown by the photograph here reproduced.

East of the exposure which has just been described, along the path through Angrogna to Torre Pellice, the beds all consist of the ordinary mica-schist, dipping south-east.

Fig. 9.—*Veins of gneiss (aplite) in the 'pietre verdi' series, Angrogna Valley.*

The aplite-veins run obliquely upward across the right-hand lower corner; one occurs just above the lower margin and below the oblique series.

5. *The Pellice Valley.*—According to Zaccagna's description and map,[1] the 'central gneiss' crosses the Pellice Valley near Bobbio Pellice; it occupies the area between the Rio Subiasco and the Rio Cruello, the town being on the eastern margin. At Bobbio the main valley is occupied by moraine, and the hill-slopes are so wooded and cultivated that no exposures could be found; to the west, however, a small footpath (named the Via Podio) branches from the Villanova bridle-path and ascends through some orchards to the

[1] 'Sulla Geologia delle Alpi occidentali,' Boll. R. Com. geol. Ital. vol. xviii. (1887) p. 384, pl. xi.

north. Five minutes' walk along this, in a field north of the path, there is an exposure of a pale-coloured, foliated, fine gneiss. The rock is worked here, and the quarry is known to the peasants as the 'Rocca Bianca.' The actual junction cannot be seen, but brown mica-schists can be found at a little distance above and below it. The foliation dips about 20° west, and is approximately the same as that of the surrounding schists. In the Cruello Valley there are numerous blocks of gneiss scattered about the lower part of the stream; as this is followed to the north, the schists become coarser and very contorted. The valley, however, is closed by two vertical side-walls and a waterfall, which may mark the junction with a northern mass of gneiss. But the path towards Malpertus shows only the ordinary mica-schists, and the peasants whom I asked could not tell me of any place where the gneiss occurred, except at Rocca Bianca; and as they all immediately recognized the specimens from that quarry, some value may be attached to their evidence.

All, therefore, that can be safely asserted about the gneiss here is that it occurs as a thin sheet or dyke, which is probably only an offshoot from a mass to the north, between Bobbio and Cima Chiapis, though it is possible that it is not at all or but slightly exposed on the surface.

A more extensive exposure in the Pellice Valley occurs on the south bank east of Villar Pellice; the rock is here a coarse augen-gneiss, with the minerals as usual all strikingly fresh and pale. It is worked in a number of quarries, the line of which is connected by a series of crags which stand out above the soft schists and talus. Being unfortunately compelled to leave the Pellice rather hastily, we were unable to examine the field relations of this band of gneiss. It must therefore be here also left doubtful whether the rock is anything more than an intrusive sheet. The northern slopes of the Pellice Valley all appear to be made up of the schist, and there is therefore seemingly no connexion between the gneiss on the southern bank of the Pellice and the outcrop in the Angrogna Valley.

6. *Barge.*—Gastaldi has described the occurrence of the 'central gneiss' at Barge, and has inferred therefrom that it is a continuation of the same rock seen farther west near Ostana, here brought up to the surface by a fold. Zaccagna, however, whose Section II. crosses the country a little north of this town, does not admit the occurrence of the gneiss there. The rock is one of the pale-coloured, coarse augen-gneisses, exactly similar to that which he has elsewhere described as 'central gneiss.' The foliation dips S.W., as does also that of the mica-schists which succeed it to the west: I had not, however, the time to search for a junction, and indeed should hardly expect to find one that would be at all satisfactory.

After passing the 788-metre point the schists dip eastward, but they subsequently become horizontal, and at a sharp bend in the road at the 833-metre level the schists are black and dip south-west.

7. *Crissolo.*—Zaccagna's main section through the Cottians crosses the valley of the Po at Crissolo and thence continues east-

ward, traversing the band of 'central gneiss.' That geologist has described the sections along this line with much care. Hence it was natural that I should expect to discover much closer agreement with the facts than in regions to the north, where the lines must have been hastily and diagrammatically sketched in. I therefore turned to the valley of the Po in the hope of finding the gneiss exactly where Zaccagna has placed it in his map. In this I was not disappointed: the gneiss can be seen in numerous roadside exposures between the hamlet of Calcinerè, west of Paesana, and the western end of a gorge due south of Crampetti. The gneiss forms steep, barren, craggy slopes, easily distinguishable from the softer and more fertile schists.

The section which best shows the relations of the gneiss and the schists occurs on the south bank of the river near a footbridge, at the upper end of a gorge east of Crissolo. The base of the hillside here is of coarse augen-gneiss, which is covered by the schists. The normal schist at more than 20 feet from the gneiss is a thin-bedded lead-coloured rock, with some interstratified amphibolites.

As we approach the gneiss the schists become coarser, till they form a gneissoid mica-schist—such as is generally observed near the contact with the Waldensian gneisses throughout the Cottians. The lead-coloured schists contain much material that can be identified as having been originally clastic grains; as we approach the gneiss this lessens in amount and water-clear quartz-felspar mosaic becomes the chief constituent. This is associated with numerous garnets, and some muscovite, epidote, and chlorite; there is also some indeterminate material which represents the less altered part of the original rock. Still nearer the gneiss the garnets disappear, but some earthy grey zoisite-aggregates represent the original constituents of the 'pietre verdi'; the bulk of the rock is formed of white mica, orthoclase, and quartz-orthoclase mosaic.

In addition to this contact-metamorphism, further proof of the intrusive nature of the gneiss in this section is afforded by some dykes of aplite which strike off from the gneiss; these are best seen where they cross some bands of amphibolites which occur in the schists. Owing to the great difference in the chemical composition of the aplite and the amphibolites, the junction between them is much sharper than that between the aplite and the mica-schists; it is very irregular, sending small projections into the amphibolite in a way that clearly shows the intrusive nature of the former. Unfortunately, it was not possible to trace the aplite-dyke into the gneiss, as the junction was hidden by moraine matter, and it was not even possible to be absolutely certain that the amphibolites were *in situ*. Their occurrence as blocks along a definite narrow line, however, rendered it highly probable, and any doubt was removed by the discovery at the foot of the slope of a large boulder of mica-schist containing a vein of amphibolite.

There is, moreover, a marked discordance between the strike of the gneiss and that of the schists, which, in the absence of any evidence for a fault, affords further proof of intrusion.

IV. Conclusions as to the Relations of the Beds.

Prof. Bonney has recently insisted on the great difficulties in the way of geological mapping in the Alps,[1] and though in the Eastern Cottians there is not much difficulty from snow or glaciers, the great extent of the moraines and vineyards in the valleys, and of the pastures on the higher slopes, prevents any detailed mapping of much of the area. The ruggedness of the country, the depth of the valleys, and the lack of accommodation add further obstacles to the investigation by causing so much of the time to be necessarily spent in walking to one's field of work.

It was impossible, in the short time available for field work, to prepare any detailed map of the geology of the area, or even to follow, as I had intended, the whole length of the junction of the gneiss and the schists. This has been rendered less necessary by the clearness of the sections at some points. A rough sketch-map of the area is appended, on which the main facts have been inserted (see fig. 1, p. 238), and it is perhaps advisable here to summarize briefly the evidence afforded by the foregoing descriptions.

As has been already remarked, according to the generally-accepted theory, the 'central gneiss' is the lowest of a three-fold series of Archæan rocks, and its position at the base of the series is due to its being the oldest of the three, the others having been deposited upon it. Against this view the evidence now presented is fairly conclusive. It will be generally admitted that if this be true, a strong unconformity must occur between the schists and the gneiss; in support of this, it is only necessary to refer to the map of Gastaldi reprinted on p. 240 and to his sections, such as that from Roche Melon to Lanzo[2] or at Monte Resta[3]; the section of Dr. Gianotti[4] shows the same for the neighbourhood of Chialamberto.

With such an unconformity it is incredible that no fragments or pebbles of the gneiss should occur in the schists. The latter are a very extensive series of deposits, and contain several beds of conglomerate, such as that at Tredici Laghi and under Punta Bruta. But in no case do fragments of the 'central gneiss' occur in them; a section of the Tredici Laghi conglomerate in the schist series shows that the pebbles consist of a felspar-zoisite aggregate with numerous crystals of rutile and some small flakes of biotite. These pebbles are very dusty, and their outlines are rounded as if by crushing; they are set in a matrix of a water-clear mylonitic mosaic of quartz and felspar, which contains long blade-like crystals running round the inclusions. The evidence of the slide is not conclusive, but the rock appears more probably to have been formed by the crushing of a felspar-conglomerate than of an augen-gneiss.

At not one of the sections examined was there any evidence of

[1] Bonney, 'On the Crystalline Schists and their Relation to the Mesozoic Rocks in the Lepontine Alps,' Quart. Journ. Geol. Soc. vol. xlvi. (1890) pp. 187, 188.

[2] Gastaldi, 'Studii geologici sulle Alpi occidentali,' Mem. descriz. Carta geol. Italia, vol. ii. (1874) pl. i. f. 2.

[3] *Ibid.* vol. i (1871) pl. v.

[4] Gianotti, *op. jam cit.* pl. v.

the derivation of the schists from the gneiss, or of any erosion of the surface of the latter.

In regard to the possible alternative theory of the gneiss being faulted up through the schist, the evidence is also strong, though it is again all negative. The absence of any slickensides or fault-rock along the junctions, the sharpness of the junction where the gneiss adjoins rocks of dissimilar composition and its indefinite nature at places where the gneiss and the schists are of similar chemical composition, and, finally, the great irregularity and complexity of the faults and thrust-planes that would be necessary to account for the field relations of the two, all combine to dismiss this hypothesis.

The positive evidence, however, as to the relations of the two series is fairly complete. It may be divided into four groups.

1. Contact-Phenomena. (a) *In the Gneiss.* Zaccagna has remarked on the fact that the 'central gneiss' passes into a true granite when at some distance from the junction,[1] a fact which he noted in the valleys of the Pellice and the Chisone; Baretti has described the same in the Paradiso massif.[2] We may, therefore, to some extent regard the foliation as a marginal structure, such as that which is not uncommon around unquestionably intrusive granites.[3]

When the rock is examined close to the junction, it can be gradually traced from a coarse to a fine gneiss. This may be seen around the Paradiso massif, as below Casa Ortiera, at Fornielli, near Bussoleno, on the banks of the Chisone, 1½ kilometre above Perosa, and is especially well shown at the junction in the Po Valley below Crissolo; at this locality the fine gneiss passes into a compact aplite. In other places the margin of the gneiss has incorporated sufficient of the neighbouring schists to considerably affect its general character; in extreme cases the gneiss has been altered into a greenish talcose gneiss, as near Chialamberto and Perosa.

(b) *In the Schists.* The alterations here vary greatly, according to the nature of the rocks with which the gneiss is in contact. When the rock is a quartzite it is converted into a quartz, as at Casa Ortiera; amphibolites and epidiorites are converted into glaucophane and hornblende-schists, while the mica-schists are rendered gneissoid at the contact and richly garnetiferous farther from the actual junction. Sillimanite, kyanite, cordierite, and other minerals are also developed, while a band of an intensely altered, decomposed rock often occurs along the actual contact-line; this is especially well shown south of Chialamberto and in the Po Valley opposite Ostana.

2. Included Fragments. Around the margin of the Paradiso massif, as along the Vonzo Valley, in the gneiss of the Roc del

[1] Zaccagna, 'Sulla Geologia delle Alpi occidentali,' Boll. R. Com. geol. Ital. vol. xviii. (1887) p. 379, and elsewhere.

[2] Baretti, 'Gran Paradiso,' Atti R. Accad. Lincei, ser. 3, Mem. vol. i. pt. i. (1877) pp. 208, 210, 214.

[3] See Rosenbusch, 'Mikroskop. Physiogr. d. Massigen Gesteine,' 2nd ed. (1887) vol. ii. p. 41.

Pelvo at the end of the Bocciarda Valley, at Mustione, etc., fragments of the amphibolites of the mica-schist series are included in the gneiss; the contact-alteration on the margin of the inclusions, and the flow of the gneiss around them, prove that they are fragments of the schists caught up by the molten rock.

3. Apophyses from the Gneiss. Opposite Ostana in the Po Valley, near Bobbio in the Pellice Valley, and below Pra del Torno in the Angrogna Valley, dykes of aplite, which present all the characters of apophyses from the gneiss, break through the schists; in the last case quoted a complete passage can be traced from the fine-grained aplite to a well-foliated gneiss.

4. Transgressive Junctions. Cases of these are the contact of the gneiss at Bussoleno with the calc-schists and gneissoid mica-schists; of the gneiss on the south side of the Valle Grande with the 'pietre verdi' series, quartzites, and mica-schists; at the upper Col de Vento, where it works across from the serpentine to the calc-schists and dolomite; the discordance of the strike of the second series around Crissolo, where, according to a manuscript map prepared and kindly lent to us by Dr. Gianotti, the gneiss transgresses from the mica-schists to the calc-schists.

5. The up-tilting of the schists at their contact with the gneiss at the Roc del Pelvo, and the irregularity of the line of junction of the two rocks—when specimens showing it are examined under the microscope—are further proofs of the intrusive nature of the Waldensian gneisses.

V. The Contact-Metamorphism.

The normal phenomena of contact-metamorphism are well shown around the Waldensian gneisses, and the development of new minerals has sometimes taken place on an extensive scale. Among others the following have thus been formed: quartz, white mica, biotite, orthoclase, microcline, oligoclase, garnets, kyanite, epidote, zoisite, and sphene. The extent to which this has proceeded varies enormously; thus the quartzites of the Valle Grande have been converted into quartz-schists along only a very narrow band; at the Roc del Pelvo, in the Comba di Bocciarda, new minerals have been developed for merely a short distance from the gneiss, while the alteration around the dykes of the Angrogna Valley only affects the neighbouring rocks over a breadth varying from ½ to about 2 inches. In other places, as in the Po Valley, the rocks have been intensely altered for 50 feet from the margin. There is, however, nothing in this to justify the charge of capriciousness often made against contact-metamorphism: it may be selective metamorphism, but good reasons can be found to explain the selection.

The variation in the extent to which this action has proceeded around the Waldensian gneisses seems to depend on two main factors,

—the bulk of the intrusive rock and the nature of the beds with which it has come in contact. Thus, as illustrations of the former, we may refer to the very thin contact-zone around the Angrogna dykes, which are apparently but tongues intrusive into the schists, so that no continued flow of molten matter ever occurred through them. The dyke at the upper Col de Vento is larger and probably rose to a considerable height above the present level of the ridge; a wider zone has therefore been affected. Around the gneiss massifs the contact-metamorphism is much more strikingly developed; here the extent varies according to whether the gneiss meets the schists as a vertical wall, as it does in the gorge of the Comba, or forms a low bank upon which the schists rest, as in the valleys of the Po and the Dora and in the Paradiso massif on the south side of the Valle Grande. In the latter cases the contact-metamorphism is most strongly marked because the schists then acted, to use the conventional illustration, as a 'piecrust'; they were in contact with the gneiss over a wide area, and through them the heat given off by the consolidating rock was slowly conducted.

The second condition which determines the extent of the metamorphism is the nature of the rock in contact with the gneiss. Where this is one of the amphibolites or other rock of the 'pietre verdi' group, the junction is sharp and definite; where the older rock is of a comparatively simple composition, such as a quartzite, it may be rendered more schistose, but few secondary minerals have been developed in it. At places where the gneiss has been intruded into a rock of a similar composition, such as mica-schist, a much greater change has been effected; the mica-schists have then been rendered gneissoid, and it is often difficult in the field to determine the exact line of separation between the two rocks. Thus, in the sections on the south side of the Chisone, east of Meano, we were not at all sure—in the field—of the exact position of the contact; the microscope, however, at once enables the two to be separated.

M. Michél-Levy has pointed out similar features in the contact-phenomena of the gneiss of the Central Plateau of France. Thus he shows [1] that, where the gneiss (or foliated granite) occurs in great mass and is intruded into rocks which are also acid in character, they are united by a passage-zone combining the characters of the two rocks. When, on the other hand, the mass of intrusive rock is comparatively small, as in a dyke, or where it cuts through rocks of a very different chemical composition, then the contact is very sharp.[2]

In concluding this section it may be remarked that the contact-metamorphism affords additional evidence as to the conditions under which the gneisses consolidated. Considering the massiveness

[1] Michel-Lévy, 'Compte-rendu de la Course du 19 août, de Semur à Saulieu, par la Motte-Ternant,' Bull. Soc. géol. France, ser. 3, vol. vii. (1879) pp. 852, 853.

[2] *Id.* 'Compte-rendu de la Course du 19 août, d'Avallon à Chastellux, *op. cit.* p. 845; 'Compte-rendu . . . à Alligny, Goie, Pensières,' *ibid.* p. 872 and 'Compte-rendu . . . de Semur à Saulieu . . ., *ibid.* pp. 853, 854.

of some of the intrusions, the contact-alterations are comparatively slight, and we have no such striking changes as those to be seen around the Biella porphyries, for example. This therefore suggests that the rock when intruded was not at a very high temperature, but in the viscid condition of a mass that has undergone partial consolidation. This is in full agreement with the evidence of the fluxion-structures. It is probable that most if not all of the true fluxion-gneisses were formed under similar conditions, and we cannot therefore expect contact-metamorphism so extensive as that produced by the intrusion of rocks, all the constituents of which were molten at the time of injection.

VI. The Origin of the Gneissic Structure.

(a) *The Igneous Gneisses.*—Before Darwin's[1] discussion of the subject in 1846, the view of the origin of the foliated rocks by original sedimentation had been universally held. Though the objections Darwin advanced have now been generally recognized as insuperable, the theory long flourished and lingers yet. In its stead have been substituted the agencies of dynamo-metamorphism, fluxion in semi-viscid consolidating rocks, and a more local combined fluxion and concretionary action. The first of these is that which is most widely applicable and is the real cause of the parallel foliation of rocks of very different composition over wide areas, *i.e.* of all cases of regional metamorphism. But that this is not a universal explanation is now admitted. Thus it has long been known that many intrusive rocks which are normally granitic in structure become foliated around the margins and in the apophyses which run off from them. Prof. Rosenbusch,[2] for example, clearly recognizes gneisses thus formed as well as those due to dynamo-metamorphic action. So also do MM. Michel-Lévy and Barrois.[3] In England the same theory has been extended to cases previously regarded as due to dynamo-metamorphic action. Thus it has been applied by Prof. Bonney and General McMahon[4] to the foliated gabbros of Cornwall, by the latter author[5] to certain gneissose granites of the Himalaya, by Prof. Bonney and the Rev. Edwin Hill[6] to the banded gneisses of Sark, and by Sir Archibald Geikie[7] to many Archæan gneisses. Further illustrations could easily be added, but this is

[1] Darwin, 'Geological Observations on South America,' 1846, chap. vi.

[2] Rosenbusch, 'Mikrosk. Physiogr. Mass. Gesteine,' 2nd ed. vol. ii. (1887) p. 41.

[3] Barrois, 'Le Granite de Rostrenen, ses Apophyses et ses Contacts,' Ann. Soc. geol. Nord, vol. xii. (1885) p. 105.

[4] 'On the Crystalline Rocks of the Lizard District,' Quart. Journ. Geol. Soc. vol. xlvii. (1891) pp. 483–491. (Further references given in footnote, p. 489.)

[5] 'Note on the Foliation of the Lizard Gabbro,' Geol. Mag. 1887, pp. 74–77.

[6] 'On the Hornblende-Schists, Gneisses, and other Crystalline Rocks of Sark,' Quart. Journ. Geol. Soc. vol. xlviii. (1892) pp. 125–127, 132–137. Note by Prof. Bonney, *ibid.* pp. 145, 146.

[7] In discussion of Prof. Bonney and General McMahon's paper, *op. cit.* vol. xlvii. (1891) p. 499.

sufficient to show that an eruptive- or fluxion-foliation is well established.[1]

Representatives of both the metamorphic and the fluxion-gneisses occur in the Cottians; thus the gabbros (or zobtenites) of Monte Viso are due to the deformation of massive gabbros, while the augen-gabbro-gneiss along the margin of the gabbro intrusion at Le Chenaillet, on Mont Genèvre,[2] appears to be clearly due to fluxion in a viscid rock near the contact.

We have then to consider which of the two explanations must be applied to the Waldensian gneisses. The field evidence at once suggests that the structure in these is a contact-fluxion. The fact that the rock is foliated on the margin, while often granitic in the centre of the massif, is not by itself conclusive. The stress of subsequent earth-movements might readily set up a deformation along the line of contact of two dissimilar rocks. But the evidence of the dykes is free from such doubts; the foliation is there parallel to the walls, and is frequently at a high angle to that of the neighbouring schists. The dykes often have an irregular course through the schists, but the foliation in them remains quite independent of that of the surrounding rocks. This appears to show conclusively that in these cases, at least, the foliation is a contact-fluxion, and has no connexion with the dynamo-metamorphism of the district.

Microscopic examination shows the identity of the structures in the apophyses and the massifs. In both the phenocrysts present true erosion-structures, as well as some which—like those from the Republic of Colombia discussed by Kuch[3]—may better be explained as due to pressure-deformation. In both, the micas and other constituents are distributed along lines of flow around the larger crystals. Finally, there is no evidence of the production of secondary minerals, such as invariably accompanies dynamo-metamorphism sufficiently powerful to produce a molecular rearrangement of the constituents.

(b) *The Clastic Gneisses.*—If gneiss be defined simply as a foliated rock consisting of quartz, orthoclase, and mica, then there are in the Eastern Cottians numerous rocks to which this name must be applied: they were clastic rocks—now altered by the intrusive Waldensian gneisses. These have been previously referred to as gneissoid mica-schists, and one has already been described on p. 259. That one serves as a convenient type, because all stages can be traced to it from a lead-coloured schist of undoubtedly clastic origin.

[1] Cases of foliation due to a kind of concretionary action on an enormous scale are probably exceptional and local. Such, however, appears to be the explanation of the foliation of some of the basic igneous rocks on the north-west coast of Lake Superior, which the writer hopes shortly to describe.

[2] Cole and Gregory, 'The Variolitic Rocks of Mont Genèvre,' Quart. Journ. Geol. Soc. vol. xlvi. (1890) p. 303.

[3] Rich. Kuch, 'Petrographie—pt. i.: die vulkanischen Gesteine:' in Reiss & Stubel's 'Geologische Studien in der Republik Colombia,' 1892, p. 61.

The differences between the clastic and the fluxion-gneisses may be very conveniently expressed in diagrammatic form by M. Michel-Lévy's formulæ. Thus, adding the letter Φ to signify foliation, the following will be the formula[1] for this clastic gneiss or gneissoid mica-schist:—

$$\Phi a\,\overline{F_7 c a_2}^{1} \quad \underline{F_9 a_1 q m}.$$

The formula for the mica-schists of the same section, where comparatively unaltered, will be:—

$$\Phi a\,\overline{F_5}\overline{M}q \quad \underline{qzm}.$$

These may be compared with that for a fluxion-gneiss:—

$$\Gamma\Phi a\gamma\,\overline{F_{5\,6} a_1} \quad \underline{m\widetilde{a_1 q}}.$$

The question therefore inevitably arises, what use is to be made of the term 'gneiss,' as the rocks included under this name comprise those formed by three different modes of origin? That the term should be used to denote a type of structure, instead of composition, is shown by the general use of such names as gabbro-gneiss. The question now is whether the term should be restricted to the igneous or clastic varieties. Different answers have been given, according to which rock was the prevalent one in the district studied. Thus M. Michel-Lévy,[2] working among the clastic gneisses of the Central Plateau and Britanny, urges the necessity of limiting the term to these, whereas Prof. Lehmann, working among the granulitic gneisses, urges that all the altered sediments should be excluded.

In the case of so old a term, it is useless to attempt to determine the matter by the Morison's Pill of priority. It therefore seems advisable to retain the word in a general sense, and add some prefix to denote the nature of the origin of the rock.

Consequently the writer suggests the appended classification of gneisses, separating those in which foliation is an original structure from those in which it has been secondarily produced; the latter series may be subdivided according to the nature of the original rock. The following table summarizes the classification and terms proposed:—

A. Metamorphic.	Altered igneous rocks	or Metapyrigen[3]-gneisses.
	„ sediments	or Clastic gneisses.
B. Igneous.		Fluxion-gneisses.

[1] c=chlorite; $a_2{}^1$=actinolite; z=zoisite; F_7=sphene; F_9=garnet.

[2] 'Note sur la Formation gneissique du Morvan et Comparaison avec quelques autres régions de même nature,' Bull. Soc. géol. France, ser. 3, vol. vii. (1879) pp. 870–871.

[3] From πυριγενής, formed by fire.

VII. The Age of the Waldensian Gneisses.

In Part IV. of the present paper the evidence has been summarized to show that, whatever may be the age of the gneiss, it is younger and not older than the surrounding schists. If, therefore, we wish to fix a minimum age for the rock, it is necessary first to determine the age of the schists. This question has been twice discussed in recent years by Prof. Bonney and Signor Zaccagna, who both agree with Gastaldi, Baretti, and other Italian writers; to these must be added the name of Prof. F. Sacco,[1] who, in a recent paper, accepts the Laurentian and Huronian correlation of the beds.

Élie de Beaumont and Fournet held that the schists were Jurassic, but their arguments were not in accord with modern methods; their view has, however, been again expressed recently by Prof. Stanislas Meunier[2] in a map in his 'Géologie Régionale de France.' Lory, on the other hand, assigned the 'schistes lustrés' to the Trias; this he taught in 1861, and reaffirmed in his latest utterances.[3] He originally assigned[4] this age only to the calc-schists that form the upper part of the series, but ultimately found it impossible to separate these from the lower mica-schists, and thus carried his line of Trias as far east as the junction with the Waldensian gneisses near Susa. This view was based on his mistaken identification of the whole of the 'Calcaire du Briançonnais' as Liassic; the lowest cargneules and dolomites of these are now universally admitted on palæontological grounds to be Triassic.[5] The schists below them are, therefore, either Palæozoic or pre-Palæozoic. Lory would no doubt have accepted this change; he would have argued that all the evidence which made him originally assign the 'schistes lustrés' to the system immediately preceding the limestone series was quite unaltered, and that this simply involved calling the schists Carboniferous or Permo-Carboniferous instead of Trias. This would, of course, be a mere matter of detail, and would not affect the principles involved in the discussion.

It therefore becomes necessary to consider what are the oldest unaltered fossiliferous rocks in the district, and what are their relations to the Cottian schists.

Along the eastern side of the Cottians the oldest fossiliferous beds are the Pliocenes, along the extreme edge of the crystalline area;

[1] 'L'Age des Formations ophiolitiques récentes,' Bull. Soc. Belge Géol. Pal. vol. v. (1891) Mém. pp. 60–95.

[2] Paris, 1889, p. 430.

[3] 'Sur la Constitution et la Structure des Massifs de Schistes cristallins des Alpes occidentales,' Congrès Géol. Internat., 4^{me} Sess. Londres, 1888, Compte-rendu (1891). pp. 86–103.

[4] Bull. Soc. Stat. Isère, ser. 2, vol. vii. (1864) p. 94 (§ 298); *ibid.* vol. v. (1861) p. 88 (§ 43).

[5] See Diener, 'Gebirgsbau der Westalpen,' pp. 18, 19.

but in the Maritime Alps representatives of all the principal systems, from the Carboniferous upwards, occur on both flanks of the main chain. Traced north from the Apennines and the Maritimes, the Carboniferous beds can be followed with some interruptions along the western slope, through Briançon to the base of Mont Thabor. Of the age of these beds there can be no question; they have been described by Fournet, Lory, Zaccagna, and more recently by Kilian: they are not very fossiliferous, but the plants recorded[1] from Monestier de Briançon, Puy St. Pierre, Chardonnet, Col de Buffer, etc., are sufficient to precisely fix their age. The Carboniferous is overlain by a series of rocks described by Zaccagna as Permian, which are doubtless a portion of the Poikilitic series; these beds in several places distinctly overlap the Carboniferous and unconformably overlie the calc-schists. Thus, in Zaccagna's section from St. Paul across the Monviso to Rocca Cavour, the Carboniferous beds are not included, but Pointe de Mary is capped by Permian beds, resting unconformably on the calc-schists. The basal conglomerates of the Permo-Triassic series overlie the schists and contain numerous fragments both of them and of the igneous rocks with which they are associated. The Carboniferous rocks, however, are in no place found in superposition to the schists, nor are fragments of the latter met with in the former; Kilian has, therefore, suggested the view that the schists are probably of Carboniferous age and represent the altered eastward continuation of these. He says "le terrain houiller disparaît à l'est d'une ligne Modane-Briançon-Saint-Paul, et *semble céder la place aux schistes lustrés*."[2]

This view has been strongly opposed by Bonney and Zaccagna, who agree in assigning the whole of the schists to the pre-Palæozoic. Prof. Bonney has given[3] a section across the pass of Mont Genèvre and the Col de Sestrières, in which he limits the Mesozoic series to the upper part of Monte Chaberton, including in the Archæan the whole of the base of the mountain below the level of the Italian forts on the road from Cesana to Clavières, and all the hills on the east side of the Dora Valley.

During the present year, however, the search for radiolaria which has been stimulated by the remarkable results obtained by Issel, Parona, and Pantanelli in Liguria, has been rewarded by a discovery by Prof. Parona which has thrown an entirely new light on the whole question. This is no less than the occurrence of a radiolarian schist, or 'phthanite,' or cleaved radiolarian mud included in the calc-schist series. Prof. Parona[4] has described the stratigraphical relations of this rock, which occurs interbedded in some green and

[1] Lory, Bull. Soc. Stat. Isère, ser. 2, vol. vii. (1864) pp. 26, 27.

[2] W. Kilian, 'Notes sur l'Histoire et la Structure géologique des Chaînes alpines de la Maurienne, du Briançonnais et des Régions adjacentes,' Bull. Soc. géol. France, ser. 3, vol. xix. (1891) p. 580.

[3] Quart. Journ. Geol. Soc. vol. xlv. (1889) p. 80.

[4] C. F. Parona, 'Sugli Schisti silicei e radiolarii di Cesana, presso il Monginevra,' Atti R. Accad. Sci. Torino, vol. xxvii. (1892) pp. 306–318.

reddish siliceous schists on the south side of Monte Cruzeau, and close beside the great mass of serpentine cut through by the road from Fenestrelle to Cesana. The point at which the beds occur is on a line between the great mass of Triassic limestone that forms the Gran Roc and Roc del Boucher, with some smaller exposures of the same rocks marked by Vasseur and Carez north of Monte Cruzeau. It seemed probable, therefore, that the fossiliferous phthanite might be really a member of the Trias series folded in with or faulted down into the schists. Prof. Parona does not consider this hypothesis in his paper, and I therefore thought it advisable to examine the area independently. Before doing this, however, I examined part of the Roc del Boucher limestone and its basal graphitic beds, and worked three times over the Triassic series of Chaberton; but in neither could I find any trace of the phthanite. Nor is there any evidence that would suggest an infold of the Trias in the schists at this point. Moreover, in working along the Fenestrelle road from Cesana, a few thin bands of a similar phthanite and siliceous schists are found to occur interbedded in extremely typical calc-schists.

[Dr. Brugnatelli has announced his intention of describing fully the stratigraphical relations of the phthanites (Parona, *op. cit.* p. 306). I did not therefore attempt to trace the beds to the north, and prefer to leave any further description till after Dr. Brugnatelli's memoir has appeared. I must apologize to him for having possibly to some extent anticipated his conclusions, but it appeared absolutely necessary to insert these remarks in the discussion of the age of the schists.]

I was consequently compelled to abandon the hypothesis which I went to Cesana expecting to be able to prove, and can see no escape from the conclusion that the radiolaria are of the same age as the calc-schists.

It is somewhat unfortunate that the only fossils found, or which are likely to be found, are radiolaria, because their evidence as to the age of the deposits in which they occur is very unsatisfactory. The radiolaria are also in a very imperfect condition of preservation, but no doubts as to their authenticity can be entertained, as Prof. Nicholson and Dr. Hinde both express themselves quite satisfied with the evidence of the slides prepared from the material which I collected. Dr. Rust, who has examined slides lent by Prof. Parona, not only identifies the fossils as radiolaria, but suggests that they are possibly Tithonian in age; the stratigraphical evidence is, however, conclusive against the latter opinion.[1]

Prof. Parona has figured a good number of the radiolaria, and has been able to determine the presence of 21 genera and even to identify 7 species. It is probable that better indications as to the age of a radiolarian fauna will always be obtained by the comparison of lists of genera than of species; more reliance must be placed on the general facies of faunas than on the number of species common to

[1] Parona, *op. cit.* p. 316.

the two. The Cesana radiolaria include two genera peculiar to the Palæozoic, though there are some previously known only in the Mesozoic. Prof. Barrois[1] has recently announced the discovery of a pre-Cambrian radiolarian fauna; the members of this, according to M. Cayeux, all belong to the Monosphæroidea. The Cesana fauna is, however, much more specialized than this, and includes such comparatively advanced forms as *Rhopalastrum*. The Ordovician fauna described by Dr. Hinde[2] all belongs to the Spumellaria, with the exception of some doubtful species; and, moreover, of this subclass only the two orders Beloidea and Sphæroidea are represented. The Cesana fauna appears of a more recent type than this, and Rust and Parona would even place it in the Mesozoic. It includes six genera of Nassellaria, while the Spumellaria are represented by the Prunoidea and Discoidea, in addition to the Sphæroidea.

Few geologists would be likely at present to argue that the mere presence of fossils in a bed is sufficient to disprove its Archæan age; but the general aspect of the radiolarian fauna is strongly in support of the view of the Palæozoic, and even of the Upper Palæozoic, age of the Cesana schists, a view which was so strenuously urged by Lory (though with a slight difference in nomenclature), and has been re-suggested by Kilian from purely stratigraphical considerations.

We must, therefore, conclude that the Waldensian gneisses are later than beds which are probably Palæozoic and may possibly be Carboniferous. This gives the maximum age. The statement has been made that pebbles of the 'central gneiss' occur in the conglomerates of the Cretaceous; I am not aware that this has been asserted by any competent petrologist, and as so many different rocks have been included under this name, it is probable that some fragments of the gneissose mica-schists have been mistaken for it. Dr. Gianotti, however, assures me that pebbles of the gneiss occur in the Miocene at Lauriano, and the accuracy of his identification cannot be questioned, though other geologists have failed to confirm it. Gastaldi also says[3] that specimens of all the rocks of the Alps occur in the Lower Miocene. This settles the latest possible date, at least for the Paradiso.

The basic igneous rocks which cut through the schists would limit the date more closely, if it could be proved that they are all of one age. The Clavières serpentine is later than the calc-schists through which it cuts, and is pre-Triassic, as fragments of it occur in the conglomerates at the base of the dolomites; and this serpentine is far more likely to belong to the basic series in the schists than to the Upper Mesozoic basic series of Mont Genèvre. None of the pre-Triassic basic rocks cut the gneiss, though they approach

[1] Ch. Barrois, 'Sur la Présence de Fossiles dans le Terrain azoïque de Bretagne,' Comptes Rendus Acad. Sci. vol. cxv. (1892) p. 326.

[2] G. J. Hinde, 'Notes on Radiolaria from the Lower Palæozoic Rocks (Llandeilo-Caradoc) of the South of Scotland,' Ann. Mag. Nat. Hist. ser. 6, vol. vi. (1890) pp. 40–59, pls. iii., iv.

[3] Gastaldi, Mem. descriz. Carta geol. Ital. vol. ii. pt. ii. (1874) p. 59.

very close to it. We may, therefore, conclude that the gneiss is later than the earlier basic series. But, until it can be determined at what period in the Palæozoic era that series was intruded, this line of argument only confirms the previous conclusions without rendering them more precise.

For a more definite determination of the age of the Waldensian gneisses reliance must be placed on the indirect evidence afforded by a study of the main dislocations of the district. It is now generally admitted that the mountains in this part of the Alps have been formed by elevations at very different epochs, from the Carboniferous (or, according to Prof. Sacco,[1] from the pre-Cambrian) to the Pliocene. The evidence for, and the influence of, the different movements, have been recently discussed by Kilian,[2] Haug,[3] and Diener.[4] The pre-Permian movements appear to have been unimportant in this district, as Diener has pointed out, though Zaccagna lays much stress upon them.

The main earth-movements of the Cottians may be divided into six groups:—

1. The east-and-west fold of the Northern Cottians, which has caused the anticlinal separating the gneiss of the Paradiso from that of the Eastern Cottians.
2. The north-and-south faults to which are due the valleys of Turras, and the uppermost part of the Dora Riparia.
3. The east-and-west compression to which is due the narrow north-and-south chain from Bric Bouchet to the Monviso.
4. A series of powerful thrusts from the west, which has pushed the Trias on to the calc-schists—as in the north-eastern spur of Monte Chaberton and in the Roc del Boucher, and has contorted the dolomites to the north of Rocca Bianca.
5. An enormous gabbro-intrusion (possibly laccolitic) which forms the Punta del Lagho, Monte Tre Denti, Monte Robinet, and Monte delle Plate, which now occupies the centre of a great circular amphitheatre, 2½ miles in diameter, formed of the schists of Rocca Rossa, Rocca Vergia, Rocca del Mortai, and doubtless also the Costa di Plantin and Costa Ciarmagranda.
6. The intrusion of the Waldensian gneisses.

[1] F. Sacco, 'La Géo-tectonique de la Haute Italie occidentale,' Bull. Soc. Belge Géol. Pal. vol. iv. (1890) Mém. p. 28.

[2] W. Kilian, 'Notes sur l'Histoire et la Structure géologique des Chaines alpines de la Maurienne, du Briançonnais et des Régions adjacentes,' Bull. Soc. géol. France, ser. 3, vol. xix. (1891) pp. 571–661; and 'Description géologique de la Montagne de Lure (Basses-Alpes),' 1888, Ann. des Sciences Géol. vol. xx. pp. 110–169.

[3] E. Haug, 'Les Chaines subalpines entre Gap et Digne; Contribution à l'Histoire géologique des Alpes françaises,' Bull. Serv. Carte géol. France, no. 21, vol. iii. (1891) pp. 169–191.

[4] Diener, 'Gebirgsbau der Westalpen,' pp. 190–218.

With the exception of No. 5, these six divisions may be arranged into two groups; the first includes Nos. 2, 3, 4, and 6, the axes or directions of which have a general north or north-westerly to south or south-easterly range; the second includes the transverse fold of the Northern Cottians. The detailed work of Kilian and Haug[1] has shown that the dislocations of the Subalpine chains to the west may also be grouped into approximately meridional and transverse series.

It is tempting to try to correlate these with the dislocations of the Cottians, but this cannot be done, except in a very general way. Kilian points out that in the mountains of Lure the north-and-south series are pre-Miocene, and the east-and-west series post-Upper Miocene. Similarly in the Gap-Digne area the N.W.-and-S.E. folds are pre-Aquitanian (Upper Oligocene) and possibly Lower Eocene, whereas the east-and-west set are mostly Helvetian (Middle Miocene), though some are pre-Aquitanian. The same probably holds in the Cottians: the east-and-west fold of the Northern Cottians is apparently connected with the Paradiso intrusion, and is probably Miocene, certainly pre-Pliocene. The Pliocene beds of the Villafranchian stage on the eastern flank have been raised over 1500 feet by a movement which closed that period.[2] As, however, the Paradiso gneiss was exposed before this, a fact proved by the evidence of the Miocene conglomerates, this Pliocene movement must have followed along the old line. The crushing of the contact-rock between the gneiss and the schists may have been caused by such later movements.

The absence of fossiliferous Tertiary beds in the Cottians prevents any such definite determination of the succession of the movements as is possible in the Subalpine mountains of Dauphiné. Nevertheless a rough order may be safely established for the remaining five sets of dislocations. No. 5 is probably Upper Mesozoic,[3] owing to the agreement of its rocks with those of the Mont Genèvre variolitic series; typical specimens of variolite derived from this mass occur in the bed of the Sangonetto above Palé. Nos. 3 and 4 are both later than the Cretaceous, some beds of which are included in the limestone series of Chaberton. No. 2 is still later, as it has cut through the overthrust limestones both at the Roc del Boucher and at Chaberton. These three sets, Nos. 2, 3, and 4, are probably more closely allied than the others; they are the result of enormous lateral compression and strain, and the secondary foliation so frequent in the schists of the district is probably due to them. The

[1] Haug, *op. supra cit.* pp. 184–187.

[2] Sacco, 'Il Cono di dejezione della Stura di Lanzo,' Boll. Soc. geol. Ital. vol. vii. (1888) p. 160; see also Gastaldi, Mem. descriz. Carta geol. Italia, vol. ii. (1874) pl. ii.

[3] The latter basic series is accepted as Upper Mesozoic (probably Cenomanien) on the authority of Prof. Sacco's demonstration that the Ligurian beds containing the serpentines of Liguria are Cretaceous and not Eocene, 'L'Age des Formations ophiolitiques récentes,' Bull. Soc. Belge Géol. Pal. vol. v. (1892) Mém. pp. 60–95.

schists and the igneous rocks of the 'pietre-verdi' group have been foliated at right angles to the axis of compression. Though I am not aware of any evidence that gives positive proof of the exact age of these dislocations, it is highly probable that they are part of the great post-Helvetian pre-Tortonian movements in which the forces that raised the Western Alps attained their maximum intensity.

The Waldensian gneisses have not been affected by any of the previous movements. The differences in this respect between the gneisses and the neighbouring schists is one of the most striking features in the Cottians. In the gneisses the minerals are all fresh, and the original fluxion-foliation undisturbed. In the schists the minerals are altered, often till no trace of the original constituents remains; instead of the felspars being water-clear, the original fragments are saussuritized or represented only by grains of zoisite, while the pyroxenes have been uralitized, and the resulting pseudomorphs, as well as the original amphiboles, have been converted into smaragdite. The changes in the structures and field relations of the rocks have been still more striking; the schists have been intensely crumpled and contorted, folds have been inverted, and the materials of the concave limb crushed into mylonites; gnarled schists have been a second time crumpled, foliation has been impressed on foliation, and fault has broken the continuity of fault. It seems almost impossible to believe that the gneisses can have remained fresh and undisturbed through the dislocations that have produced such changes in the rocks with which they are in contact; this affords another proof not only that the Waldensian gneisses are younger than the schists, but that they are later than the great earth-movements at the close of the Middle Miocene. It is quite possible that the gneiss of the enormous massif of the Paradiso was intruded somewhat earlier than that of the Eastern Cottians, and this would account for the pebbles in the Miocene. The low banks of gneiss which even now have only a very restricted outcrop, sometimes merely on the floors of the Waldensian valleys, are most unlikely to have been exposed during Miocene times.

In the Alps of Dauphiné the Pliocene movements are very feeble, but this does not forbid their powerful influence in the centre of the Cottian group, for feeble also are the movements in the Miocene there—compared with those which elevated the main chain of the Western Cottians. The elevation of the Villafranchian beds has been shown by Sacco to demonstrate an elevation of over 1500 feet, and the gneiss-intrusion may well have been contemporary with this. Paradoxical though it may appear, the evidence renders it most probable that the Waldensian gneiss, instead of being of Laurentian age, is really Pliocene, and, with the exception of the Saharian and recent alluvium and the glacial moraines, is the newest rock in the Cottians.

VIII. Summary of Conclusions.

1. The Cottian Sequence consists of:—

(a) A series of coarse-grained gneisses occurring along the line of the Eastern Cottians; for convenience of reference these are called 'the Waldensian gneisses.'
(b) A thick succession of schists which are gneissoid near the junctions with the gneisses, are mica-schists at the base, and pass upward into calc-schists.
(c) An extensive group of epidiorites, serpentines, etc. (the 'pietre verdi' of Gastaldi), which traverse the lower part of *b*.
(d) A series of fossiliferous beds ranging from the Carboniferous upward.

2. The Waldensian Gneisses. A description of their field-relations and microscopic structure is given, and it is contended:—

(a) That they occur as independent, isolated masses, and not as a continuous band having a fixed geological horizon at the base of the whole series.
(b) That instead of being basal Laurentian rocks, overlain by or faulted against the schists, they are a series of igneous intrusive rocks; this is demonstrated by
   i. The contact-metamorphism around them, both exomorphic and endomorphic;
   ii. The occurrence of apophyses of gneiss and aplite from the gneiss into the schist;
   iii. The gneiss often containing large altered blocks of the schists, and being sometimes saturated with chloritic and amphibolic material absorbed during intrusion;
   iv. The transgressive nature of the junction between the two series;
   v. The failure of any of the igneous rocks, intrusive into the schists, to cut the gneiss;
   vi. The fact that the gneiss has not been affected by the earth-movements which have crushed and contorted the schists.

3. The Paradiso Gneiss. The relations of this on one margin are also described, and it is shown that it agrees in all respects with the Waldensian gneisses, except for

(a) Its greater mass.
(b) The possibility that it was in part intruded at an earlier date.

The evidence in this case is less complete.

4. The Gneissic Structure.

This is shown not to be due to dynamo-metamorphism, but to be an original fluxion-structure formed owing to the intrusion of the rock in a viscid condition. It is, therefore, not to be expected that these fluxion-gneisses will produce such extensive contact-metamorphism as rocks intruded at a higher temperature. Other gneisses in the Cottians were formed by the dynamo-metamorphism of igneous rocks and mechanical sediments. The example of those writers who use the term 'gneiss' only in a structural sense is, therefore, followed; and the three groups met with in the Cottians are referred to as clastic gneisses, metapyrigen-gneisses, and fluxion-gneisses.

5. The Age of the Waldensian Gneisses.

(*a*) They are later than the schists, and the uppermost member of this series belongs in all probability to the Palæozoic; this conclusion is based on:
   i. The stratigraphical evidence relied upon by Lory and Kilian;
   ii. The evidence of the radiolarian fauna in the calc-schists;
   iii. The schists, however, are unquestionably pre-Triassic.

(*b*) The gneisses have not been affected by the great Miocene (post-Aquitanian, pre-Langhian, post-Helvetian, and pre-Tortonian) earth-movements which have crushed and contorted the schists.

(*c*) The elevation of the marine Pliocenes to the height of 1500 feet shows that powerful earth-movements occurred in late Pliocene times; the intrusion of the Waldensian gneiss was probably contemporary, and perhaps the cause of these.

EXPLANATION OF PLATE XV.

Fig. 1. Typical Waldensian Gneiss. From quarries at Bussoleno. $\times \frac{42}{2\frac{1}{3}}$.

The minerals shown are large, eroded, dusty crystals of orthoclase (*o*), water-clear quartz-orthoclase mosaic (*x*), numerous crystals of muscovite (*m*), and granules of kyanite (*k*).

Fig. 2. (a) Gneiss from the margin of the Paradiso massif, consisting of a fine-grained, quartz-orthoclase mosaic (*x*), muscovite (*m*), included granules of epidote (*e*) and aggregates of zoisite (*z*) and chloritic material (*c*).

(b) An included fragment from the adjoining 'pietre-verdi' series, showing the indefinite groundmass, quartz, and glaucophane (*gl*).

From the Vonzo Valley, near Chialamberto. $\times \frac{42}{2\frac{1}{3}}$.

Fig. 3. Junction of the aplite-dykes with the rocks of the 'pietre-verdi' series; from the Rocce Roccaglie, Angrogna Valley; see fig. 9, p. 257. $\times \frac{26}{2}$.

Fig. 4. Part of the thickest aplite-dyke from the same locality. It consists, in the main, of quartz-orthoclase mosaic and bands of muscovite; it contains included grains of the surrounding rocks, like that seen in fig. 3.

Figs. 5 & 6. The Contact-series at Ostana, near Crissolo, Po Valley. $\times \frac{42}{2\frac{1}{3}}$.

Fig. 5. The contact-rock; all the minerals are authigenous or due to injection from the gneiss; the rock consists of orthoclase (*o*), quartz-orthoclase mosaic, biotite (*b*), and zoisite aggregates (*z*).

Fig. 6 (a). The lead-coloured mica-schists, 100 yards from the contact.

Fig. 6 (b). The gneissose mica-schist near the contact; the principal secondary minerals produced are garnets (*gr*), often traversed by veins of chlorite, muscovite (*m*), and rutile (*n*).

All the figures are drawn under ordinary transmitted light.

Discussion.

The President felt sure that all would join in offering a welcome to Dr. Gregory on his first appearance at the Society, as an Author, since his adventurous African journey; and he further expressed a hope that, ere long, the Society would hear something of the geological features of Mount Kenya.

The paper contained some startling conclusions in respect to the lowest rocks not necessarily being the oldest; but for these we had been more or less prepared by the work of Lawson in America and of Barrow in Scotland. Hence there was no *à priori* improbability. The question was whether the evidence and arguments in this case favoured the notion of a gneiss having been intruded into schists. He (the President) thought it was so, though without further proofs as to age it might be merely an instance of an Archæan gneiss intruded into Archæan schists. Thus it became important to determine, if possible, the age of the schists. He commented on the fact that no fauna lower than the Carboniferous had been discovered in the Western Alps, and expressed curiosity to know what had become of the older Palæozoics: the discovery of radiolaria may possibly lead to results of importance in this direction.

But by far the most astonishing part of Dr. Gregory's paper is the last, where he speculates on the age of the gneiss itself, and concludes that, owing to its freedom from the effects of earth-movements, it is actually amongst the youngest rocks in the Alps. On this point, more especially, he expected an animated discussion.

Prof. Judd said that all his prepossessions were in favour of accepting the views of Dr. Gregory concerning the hypogene origin of these gneisses and their late geological age. He felt, however, that, in a district which has undergone such great movements, the evidence brought forward must be scrutinized with the most extreme care. He was not satisfied that the evidence of contact-metamorphism, of included fragments, and of apophyses of aplite proceeding from the gneiss into the schists had been established beyond every possibility of doubt.

Mr. Barrow observed that the paper before the Society might be divided into four parts. The first dealt with the evidence of the intrusive nature of the coarse gneiss; and the Author was to be congratulated on the careful manner in which he had gone over the ground, and the clearness with which he had summarized his evidence. The second referred to the contact-effects of the intrusion. But here the evidence was too vague to enable us to form any opinion as to the accuracy of the Author's views. Did he suppose that the crystalline character of the surrounding schists and gneisses was essentially due to this intrusion or merely modified by it? Thirdly, the evidence of age would require most searching examination. The movements on the margins of mountains have frequently associated fossil-bearing rocks with older crystalline schists in such a manner as to have deceived some of our most acute observers, and led to the conclusion that they were all of one age. Lastly, the fact that the great earth-movements do not appear to have effected any crushing in the coarsely crystalline rocks was not a satisfactory line of argument as to the age of the rocks. Powerful earth-movements frequently fail to crush more than the outer margins of crystalline areas; these harder rocks escaping at the expense of the softer and often unaltered sediments by which they are flanked. The latter, indeed, are frequently themselves altered to finely schistose rocks giving every appearance of a passage from one series to the other.

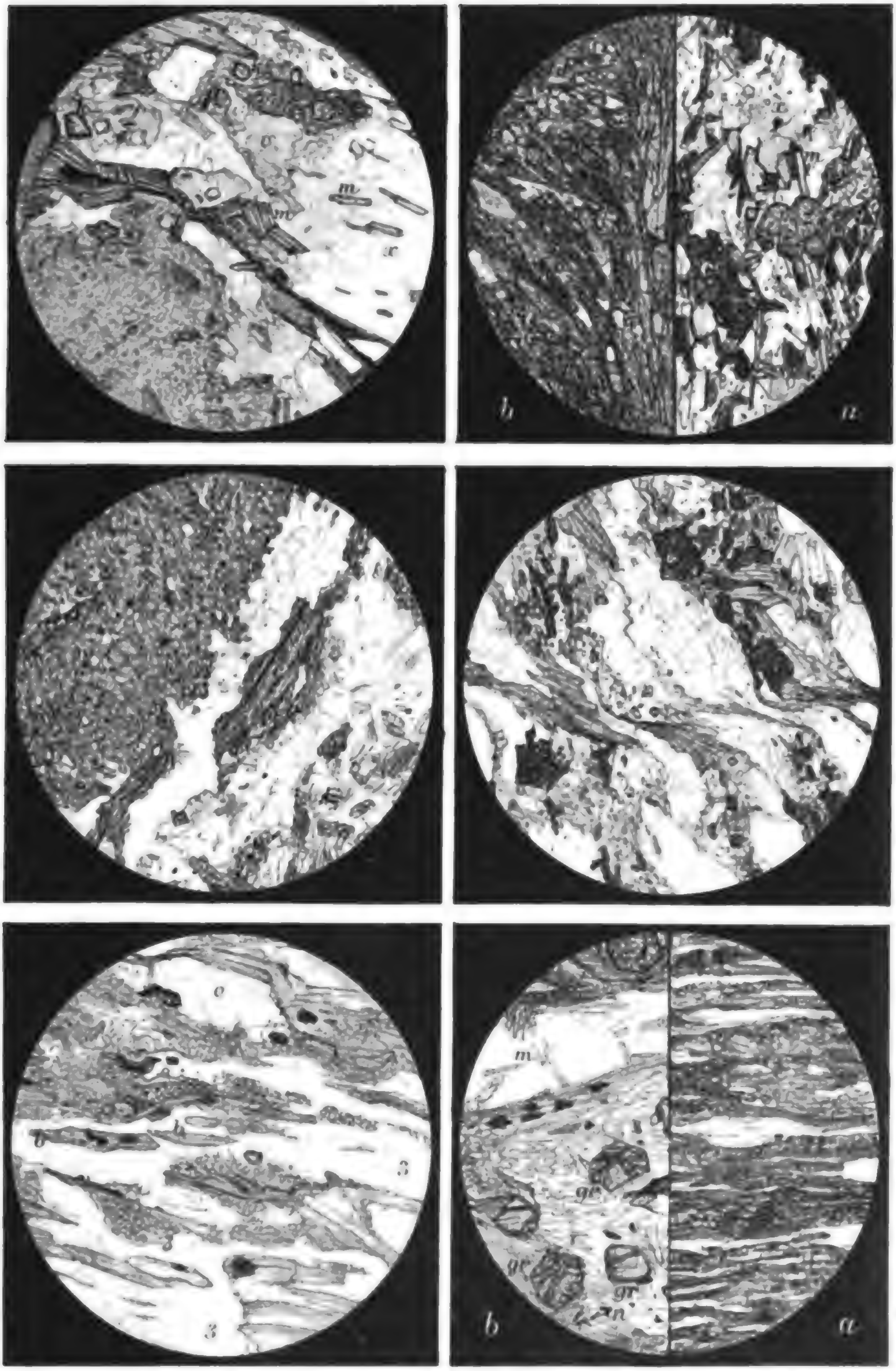
Prof. Bonney said that he had only examined these Cottian gneisses in one locality, and had found it extremely difficult to make out what their origin might be. If fluxion-gneisses, which was very possible, they were rather peculiar. He quite agreed that a group of granitic rocks existed in the Alps later than any of the crystalline schists, but that did not prove that they were Tertiary, Secondary, or Palæozoic. The discovery of radiolaria in the 'schistes lustrés' did not show that these were Palæozoic, because, if the rocks were *schists*, there would be no radiolaria remaining; and nothing was commoner in the Alps than to find wedges of Jurassic, or Triassic, or older but comparatively unaltered sediments in the crystalline masses. Also the Carboniferous rock was very apt to have its base full of material from the older underlying rock. As to the age of the gneiss, he agreed with Mr. Barrow that no great value attached to the fact of these rocks being uncrushed. He gave instances, and said he felt incredulous as to a Pliocene age, because there was no evidence, so far as he knew, of outbreaks of igneous rock of Tertiary age, except the basalts in the S.E. The Permian or some part of the Trias seemed the latest possible.

Mr. A. M. Davies said that he had accompanied Dr. Gregory on his last visit to the Cottians, and had seen the greater part of the evidence on which his conclusions were based. Some of the junctions (such as that at the Roc del Pelvo) showed striking evidences of intrusion, but there was room for much more detailed study; and the mountainous nature of the district would add greatly to the

difficulties of mapping. There was some evidence of Tertiary (or Upper Mesozoic) volcanic activity farther west, though faulted junctions prevented clear demonstration in the most desirable case. There, in the Mont Genèvre and Chaberton region, the presence of Mesozoic sedimentaries enabled one to immediately recognize folds, faults, and thrusts, the importance of which might easily be underestimated in the area of crystalline schists and gneisses.

Mr. Vaughan Jennings and Dr. G. J. Hinde also spoke.

The Author, in reply, admitted the need for caution and careful mapping. He did not think the inclusions could be segregations, owing to their difference in composition from any of the minerals of the gneiss and their resemblance to those of the altered 'pietre verdi'; segregations do occur, and are easily distinguished. No aplite-dykes occur in the gneiss, and the aplite is mineralogically almost identical with the selvages of the gneiss masses; the evidence of the Crissolo section seems conclusive that the aplite-dykes are offshoots from the gneiss. As regards the argument from the unaltered nature of the gneiss, it was admitted that rocks in mass could readily escape; but this could hardly be the case with dykes ranging from 100 feet to 1 foot in width. The absence of pebbles in the conglomerate tells also very strongly in favour of the recent age of the gneiss. The interlamination of thin beds of the radiolarian phthanites with the calc-schists renders it very difficult to explain their occurrence by any system of infolds. He had no doubt of the occurrence of igneous rocks of post-Palæozoic age in the Cottians.



1. $\times\frac{42}{2\frac{1}{3}}$ 2. $\times\frac{42}{2\frac{1}{3}}$

3. $\times\frac{26}{2}$ 4. $\times\frac{42}{2\frac{1}{3}}$

5. $\times\frac{42}{2\frac{1}{3}}$ 6. $\times\frac{42}{2\frac{1}{3}}$

F. H. Michael del. et lith. Mintern Bros. imp.

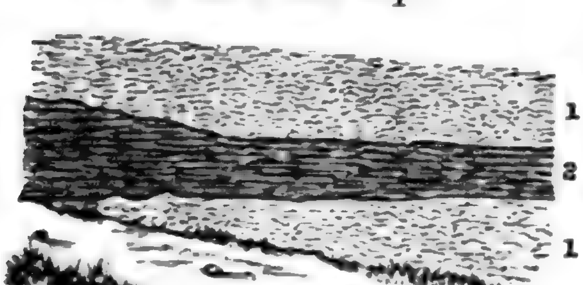
GNEISSES, APLITES & CONTACT-ROCKS

18. *On* SOME CASES *of the* CONVERSION *of* COMPACT 'GREENSTONES' *into* SCHISTS. By T. G. BONNEY, D.Sc., LL.D., F.R.S., F.G.S., Professor of Geology in University College, London, and Fellow of St. John's College, Cambridge. (Read February 7th, 1894.)

LAST year I described some modifications due apparently to pressure in certain basic dykes.[1] I am now able to supplement that account by a few notes on the changes produced by the same agency on a somewhat similar rock which, however, in all probability, was at first in a still more compact condition than any of those 'greenstones.'

In the year 1880 I noticed, near the path leading from the Bernina Hospice to the Grüm Alp (Engadine), a rather small mass of a green schist, so compact as to resemble a slate, associated with a fairly coarse gneiss. Their relations seemed explicable on the hypothesis of either an interstratification of materials or an intrusion of the green rock into the gneiss. Each supposition had its difficulties, and my impression was recorded in the following words:—"I can hardly believe the green rock to be anything but a schist" (meaning, according to my knowledge at that date, a rock originally sedimentary). I took away specimens and examined these afterwards with the microscope. The green rock presented the ordinary structure of a fine-grained schist; the gneiss gave some indications of a fragmental condition. But as I supposed (as I had been taught) that gneiss also was a metamorphosed sediment, this was not surprising; still it seemed strange that a rock, so little altered as the schist appeared to be, should be associated with one seemingly so much altered as the gneiss. Accordingly I deemed it best to keep the specimens in my cabinet, and to wait for further light.

Fig. 1.—*Schistose dyke by the path to the Grüm Alp.*



1. Gneiss. 2. Schistose dyke.

Gradually suspicions arose in my mind that the green schist must be a crushed diabase or kindred rock. Hence, on revisiting the Engadine last summer, I took an early opportunity of examining the locality, and was speedily convinced of the correctness of my surmise. A dyke which cuts the gneiss makes a low angle with the horizon, and sends small offshoots into the latter rock. The appearance of interstratification has been heightened by the crushing out of

[1] Quart. Journ. Geol. Soc. vol. xlix. (1893) p. 94.

the two rocks. The following words written on that occasion describe the macroscopic aspect of the green schist:—"The rock looks just like a slightly altered, poorly cleaved slate, the cleavage-structure making a low angle with the horizon and running nearly parallel with the slight foliation of the gritty-looking gneiss. The schist occasionally (especially in the inner part) seems less fissile and more massive. It has also two sets of sharply-defined joints, making angles of 75° or 80° with the horizon, and is traversed by two or three thin veins of quartz." The thickness of the dyke is rather variable: it hardly ever exceeds a yard, and is generally a foot or so less.

About a hundred yards farther on is a smaller dyke, about half a yard thick. Here some of the gneiss is much crushed, and the foliation of the two rocks is not always parallel, the structures in one place making an angle of about 20°. Rather beyond this comes a third dyke about 8 feet thick, which is less fissile and altogether more like diabase. Others were found in the neighbourhood, but further details seem needless.

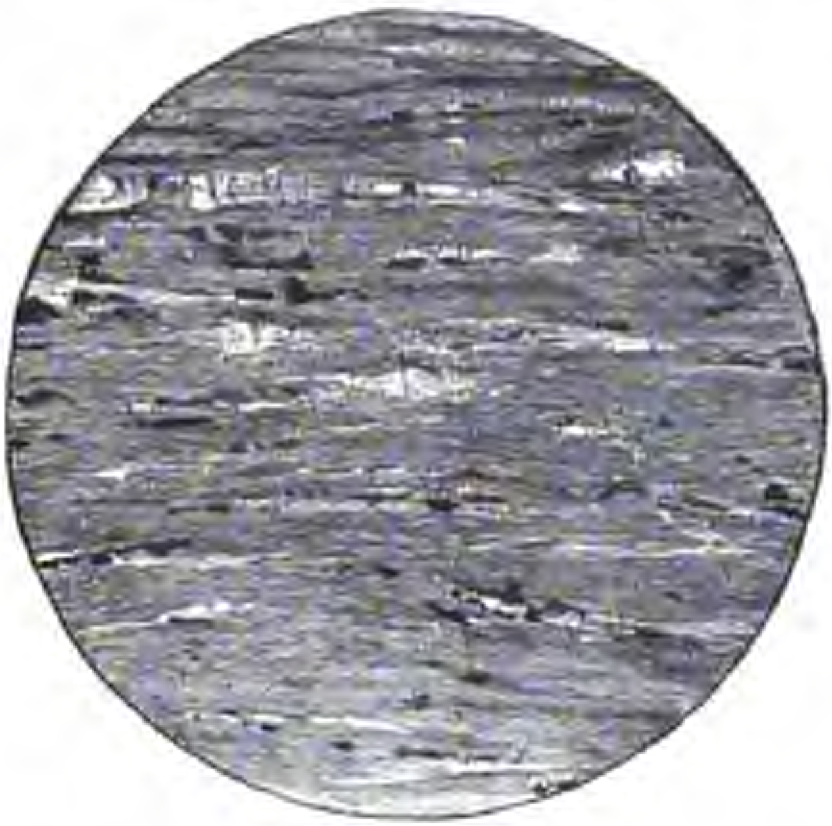
A specimen from the most slaty part of the first dyke (an inch or so from the edge) is seen on microscopic examination to be composed chiefly of three minerals, all minute. (1) A pale green, mica-like mineral in wavy films, slightly dichroic. It is difficult to be sure of the extinction; in some cases it appears to be parallel with the cleavage, in others slightly oblique. Placed at an angle of 45° with the vibration-planes of crossed nicols the films give fairly brilliant polarization-tints. Some may be a chlorite, but the general aspect of most of the mineral suggests a hydrous ferro-magnesian mica. (2) A rather granular mineral of a pale yellowish colour, which appears to be associated with an earthy dust. Some, at least, of this is probably epidote, but sphene also may be present. (3) A water-clear mineral in rather angular elongated granules. This forms a kind of matrix for the other two, and resembles a secondary felspar rather than quartz. The structure of the specimen is that of a very fine-grained but crystalline schist, and all traces of an igneous origin have completely disappeared. The specific gravity is 2·55.

A specimen, which exhibits a junction with the gneiss, is not quite so distinctly foliated as the former one, especially for about a tenth of an inch near the contact-surface. In this part it is more granular and earthy-looking and is less transparent; in one place it has a rather streaky structure. The weld between the two rocks is perfect, and the subsequent pressure, as a rule, seems not to have produced separation, except here and there, where a very small crack appears to have formed and to have been filled up afterwards with a greenish mica.

A slice cut from the middle part of the second dyke mentioned above exhibits a foliated mass of microcrystalline minerals. Among these the micaceous one already described is much the most abundant,

but it occurs in rather larger flakes, and streaky patches of it are more distinctly brown, which, however, may be due only to iron-stains. With it a fibrous microlithic hornblende may be possibly associated, but the amount is not large. Many blackish granules, more probably hæmatite than magnetite, also occur, with a somewhat streaky arrangement, as if they were due to the crushing of larger grains. In this slice the clear interstitial mineral is less perceptible, but it contains a few rather elongated patches in which the grains are larger, though generally composite. The mineral resembles secondary quartz rather than secondary felspar, and in its outer part is pierced by minute colourless belonites. The silica percentage is found to be 61·88, and the specific gravity is 2·72.[1]

Fig. 2.—*Section cut from the middle part of the second dyke by the path to the Grüm Alp.*



× 20.

A slice cut from the middle part of the third dyke shows it to be not quite so markedly foliated, and the constituents, including the clear interspaces, are more distinct. Of the mica a fair amount is of a yellow-brown colour; this has a tendency to occur in groups of a rather tufted form. Some is greenish, and may rather be, in part at least, a chlorite; while not a little, in well-formed flakes, generally smaller in size than the others, is either colourless or nearly so. Dark grey sub-translucent granules (? chalybite) replace most of the

[1] I am indebted to Mr. M. W. Travers, B.Sc., University College, London, for these determinations and that of the other specific gravities.

opacite. The nature of the water-clear mineral is not easy to determine. Some of it is more probably a secondary felspar than quartz.

On the eastern shore of the Lago Bianco a mass of schistose green rock is intrusive in a rather fine-grained, somewhat crushed-looking gneiss, which also is slightly green in colour. It runs obliquely up the hillside and must be several yards in thickness, but as there is no continuous section the exact figure is not easily ascertained. This rock is coarser in texture and less schist-like than the others. On examination with the microscope it exhibits numerous patches and occasional streaks occupied by an aggregate of minerals, in certain cases apparently an actinolitic hornblende, in others a chlorite, some of the latter being fairly dichroic and changing from a pale tawny yellow to a distinct green (a usual type). The patches (where hornblende is common) are often speckled with opacite. Minute mica is probably present, but is less distinct than in the other cases.

Rather lenticular 'earthy-looking' patches (not compound in structure) are numerous; these doubtless represent crushed and decomposed felspars, and in one or two, which retain some clearness, the oscillatory twinning of plagioclase can be still recognized. Water-clear grains, often pierced by minute belonites, are fairly common. Most of them present on the whole a closer resemblance to a secondary felspar, though quartz also may be present. There are granules and grains of iron oxide, the larger most like ilmenite. A little calcite is also present. Though a schistose structure is distinct, the rock still retains some likeness to a diabase and would be recognized more readily as a crush-product of a fine-grained dolerite. Its specific gravity is 2·83.

From these facts it follows that, in certain cases, a rock of igneous origin may be so completely changed by pressure and its indirect consequences as to be readily mistaken for a compact and not very much altered sediment.[1] For this to happen it is, I believe, requisite that the original rock should be glassy or almost in this condition, viz. the segregated minerals, as a rule, should be micro-

[1] The rock from the Llyn Padarn district which I described in 1879 as a black slate (Quart. Journ. Geol. Soc. vol. xxxv. p. 312) is a similar case. As rightly determined by the Rev. J. F. Blake (*op. cit.* vol. xlix. p. 456), the mass is a dyke. His specimen, which he was good enough to show me, places the igneous origin of the rock beyond doubt, though whether it be a lamprophyre (if that term bears any definite sense) is more open to question. But it differs so widely from my specimen that at first I doubted whether they came from the same mass. I have, however, revisited the place and found this to be the case. I believe that if, even in 1879, I could have examined Mr. Blake's specimen, I should have recognized it at once as a somewhat modified igneous rock. That which I did examine (and have subsequently puzzled over many a time, for I soon became less satisfied with my conclusion) was cut from a junction-specimen. As in the case described above, the effects of crushing are not very conspicuous; it is somewhat banded and curiously like a rather altered sediment. The micromineralogical structure is a very unusual one. Even

lithic. Whether the dominant secondary mineral will be mica or hornblende is probably dependent upon the chemical composition of the rock. If it be a normal basalt, we may expect the latter; if near the andesites, the former. It is interesting, however, to notice that the ultimate structure of the rock apparently depends to some extent upon the earlier one; for it is coarser in the thicker than in the thinner dykes, and in the latter becomes distinctly more compact near the margin. The peculiar structure of the junction-specimen[1] also suggests that it retains a trace of the actual selvage of the dyke. This indicates, by the way, that the structure has been acquired by direct crushing rather than by shearing (in the strict sense of this word), for the peculiar linear banding must have been obliterated, or at least rendered very indistinct, by any lateral displacements of importance.

It is also remarkable that this zone—the most glassy or slaggy of the original rock—apparently has yielded less to pressure than the part beyond, for it has a less distinct foliated structure and a stronger resemblance to a compact, somewhat decomposed sedimentary rock.

Rather compact green schists, which not seldom exhibit more or less of a slabby structure, are common in various parts of the Alps. They resemble sometimes the rocks described above, sometimes

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now, after fourteen years of study, after having examined perhaps fifty slices which might be helpful, for every one which I had then seen, I cannot find a better comparison than that the structure of the supposed slate 'resembles that of the groundmass of some of the chiastolite-slates,' though I admit that it is not a good one. We have, in short, been describing specimens which bear little resemblance one to another.

The most singular feature in my slice is the comparatively slight indication of the effect of crushing. The quartz-felsite exhibits (unless I err) a faint fluxion-structure; the porphyritic crystals of quartz and felspar are but little broken. In the intrusive rock also the microfoliation is not conspicuous till the slice is placed with the structure about halfway between the vibration-planes of crossed nicols, and the gradual change from the selvage to the coarser parts (in a thickness of about one-third of an inch) is quite distinct. Yet the fissile character of the rock, especially near the outside, is most remarkable, and even its texture on a broken edge is not unlike that of a dark slate. I have to thank Miss C. Raisin, B.Sc., for a slide cut from the same dyke (about 4 inches from the margin). In this the microporphyritic character is distinct, but the groundmass more nearly resembles that of my own slide. I am also indebted to her for slices of other dykes in the neighbourhood. A selvage remains in a slaty dyke which occurs on the more western side of the cutting at the northern end of the tunnel, but here no doubt could arise as to the nature of the rock. A conspicuously porphyritic dyke, on the opposite side of the same cutting, also exhibits a selvage. The base of this is of a dark green colour, and it remains dark between crossed nicols: the larger crystals in it are but little affected. There must be something exceptional in the effect of pressure on a compact and rather basic igneous rock. It looks as if the micromineralogical structure was developed without much fracture of the glassy material. Perhaps this is due to the intimate mixture of the chemical constituents, so that the process is more like that of devitrification.

[1] This remark applies also to the Welsh specimen mentioned in the last note.

those noticed in a former paper.[1] These green schists occupy areas sufficiently considerable to require a distinctive name, and are designated *grüne schiefer* by the Swiss geologists. Commonly they are in association with calc-mica schists (*graue schiefer, kalkhaltig*) and darkish mica-schists (*thonglimmer-schiefer*). My observations indicate the possibility that modified igneous rocks may form a large part of the *grüne schiefer*. I would not go so far as to say that the whole group consists of altered igneous rocks, because a tuff, or even a mud derived from a fairly basic rock, might be metamorphosed into one of these green schists, and I have seen some cases where the association with other schists suggested such an origin; still I am inclined to believe that the first-named one is the more common. In any case, it may be useful to bear in mind that slaty rocks, which look not much more altered than phyllites, can be produced by pressure from igneous rocks of proper constitution and texture.

Discussion.

Dr. C. Du Riche Preller referred to the so-called 'Taveyanaz' sandstone of the Glarus Alps, and also to the sernifite, as rocks having possibly some relation to those described by Prof. Bonney.

The Author said that he had not had time to examine the sernifite which Dr. Preller had kindly shown him, but he thought it was undoubtedly a sedimentary rock, though possibly it might contain comminuted igneous materials. The sandstone, he thought, must be clastic in origin.

[1] Quart. Journ. Geol. Soc. vol. xlix. (1893) p. 94.

7

19. Mesozoic Rocks *and* Crystalline Schists *in the* Lepontine Alps.

By T. G. Bonney, D.Sc., LL.D., F.R.S., F.G.S., Professor of Geology in University College, London, and Fellow of St. John's College, Cambridge. (Read April 11th, 1894.)

Contents.

I. Introduction.

My communication to the Society 'On the Crystalline Schists of the Lepontine Alps'[1] has elicited a paper from Dr. F. M. Stapff,[2] and has been noticed at some length by Prof. Heim in a recent publication of the Swiss Geological Survey.[3] The pages of this Journal, for more than one reason, cannot well be used for purposes directly controversial; so that, as I expect to find before long a more suitable opportunity and place, I content myself at present with remarking generally that Dr. Stapff's main argument is difficult to discuss, because everything turns upon the exact geological position and the microscopic structure of certain specimens, matters in which photographs are of little avail; and that Prof. Heim, as will be incidentally shown in the course of this paper, really adds nothing to his original argument. That rests, as I stated in my former communication, upon a correlation of certain rocks which I consider highly improbable, and an identification of certain minerals which I affirm without hesitation to be erroneous.

In that communication I maintained that there was (*a*) no valid proof, only a *primâ facie* presumption, that the Altkirche[4] marble was of Jurassic age: and (*b*) not only no proof at all that the Val Piora schists were of this age, but also strong evidence that they were much more ancient.

On the first issue I claimed a verdict of 'not proven.' In the hope of finding more definite evidence, even if it went against me, I have revisited the district. In 1891 I made a brief examination of the sedimentary rocks near the Furka Pass, in company with Mr. James Eccles, and last summer I spent a week in the upper part of the Urserenthal. My friend also, in the interval, went over some of the

[1] Quart. Journ. Geol. Soc. vol. xlvi. (1890) p. 187.

[2] Geol. Mag. 1892, p. 6. Since the words above were written a second paper has appeared in the same periodical, 1894, p. 152, to which also the same remark applies.

[3] Beiträge zur geol. Karte der Schweiz, Lief. xxv. 1891.

[4] This appears to be a more correct spelling than that used in my former paper.

ground, and has supplied me with much valuable information. The results of my work, I regret to say, are far from being decisive, and my only excuse for laying them before the Society is the exceptional interest of the question, and the hope that they may be useful as a record of facts of which account must be taken in framing any hypothesis.

But before proceeding further it is almost necessary, in order to dissipate a confusion which I have perceived to exist, to repeat what has been already stated in print, so far as to make clear the exact points at issue between myself and these eminent foreign geologists.

(1) I have never denied that Jurassic rocks form a part of the sedimentary belt in which the Altkirche marble occurs—I know the Alps too well to do anything of the kind. Nor do I deny that the stratigraphical evidence seems at first sight favourable to regarding the marble as merely a peculiar member of the group of Jurassic rocks. My position is, that such an identification proves, on a more careful scrutiny of the sections, to be beset with difficulties, while, so far from receiving any support from, it is contradicted by other regions of the Alps, where the sections are clearer.

(2) I have never denied that in the Alpine chain the sedimentary rocks, to say nothing of the igneous, have undergone, in consequence of the mechanical disturbances to which they have been subjected, a certain amount of structural and of mineralogical change, and might thus be termed 'metamorphic' rocks[1]; but I have affirmed, and I now do it yet more emphatically, that the results of these changes generally can be recognized, and are not comparable, in the case of the later Palæozoic or Mesozoic sediments of the Alps, with the alterations which, anterior to these disturbances, have converted into crystalline schists certain sediments of unknown antiquity. Hence I consider it better, if it be desired to avoid confusion of expression and thought, either to abstain from applying the term 'metamorphic' to the former results or to devise a new connotation for the latter.

(3) It is also necessary to repeat (strange as this may seem) that a transitional passage of a sedimentary into a crystalline rock cannot be inferred from the existence of a comparatively narrow intermediate zone in which the destructive effects of pressure have been so great as to make it doubtful whether this represents a crushed condition of the crystalline rock, with slight secondary change, or a squeezed condition of a clastic rock (especially if the fragments be derived from the crystalline one) with a similar change. Neither can identities be inferred from superficial resemblances, unless a microscopic study shows these to depend upon a real community of structure and composition.

[1] It must be remembered that certain constituents of rocks are more ready to change than others. For instance, carbonate of lime very readily crystallizes. Hence, in dealing with an apparently crystalline limestone, it is necessary to study the rock as a whole, and to pay great attention to the condition of other constituents. Silicates are more useful, as a rule, than quartz, for grains of the latter readily become enlarged and thus are apt to lose their clastic characters.

II. The Altkirche Marble.

The belt of sedimentary rocks in which this marble occurs extends from a point on the western slopes of the Oberalp Pass along the valley of the Upper Reuss and across the Furka Pass into the valley of the Upper Rhone. On the latter pass and to the east it is bounded, on the northern side, by a more or less micaceous gneiss, on the southern usually by a group of greenish schists, which are followed by the micaceous schists or gneiss of the northern slopes of the St. Gothard Pass. These greenish schists will be referred to (for brevity) as the 'Hospenthal schists.' In this communication I shall abstain from discussing the question of their origin, merely remarking that as a rule they have been greatly affected by pressure and that I rank them among the crystalline rocks of the Alps. On the slopes, however, of the Oberalp Pass, as will be indicated below, they do not immediately succeed the above-named belt. Its rocks (with the exception of the marble) are generally dark in colour (from a dull lead-blue to almost black); the marble varies from white to light grey. The belt of sedimentary rocks crops out usually on the northern slopes of the valley: good sections are not common, so much being concealed by débris and turf.

I purpose to deal with the subject by describing a series of sections (the best which I could find) from east to west, over a distance of about 11 miles in a straight line. In order to make some approach to brevity I shall suppress all minor details of structure and mineral composition, and content myself with saying that every important point in regard to similarity or dissimilarity has been carefully tested by microscopic examination of specimens collected for that purpose. As there can be no doubt that the rocks of this belt, in which the marble occurs, whatever be their geological age, are sedimentary in origin, I will refer to it, for brevity, as the 'sedimentary belt.'

(a) *Section on the higher eastern slopes of the Oberalp.*—This section has been recently exposed, in the construction of a military road leading up the mountain on the northern side of the Oberalp Pass. That road cuts obliquely across the sedimentary belt at angles of 20° or 30° with the general strike of its rocks, and enters on the northern mass of micaceous gneiss some 1600 feet above Andermatt.[1] The belt consists, on the northern side, of a rather dark phyllite,[2] interstratified with hard sandy bands, which gradually becomes more calcareous as we proceed southwards. In this part paler and more crystalline-looking layers (say from an inch downwards), which

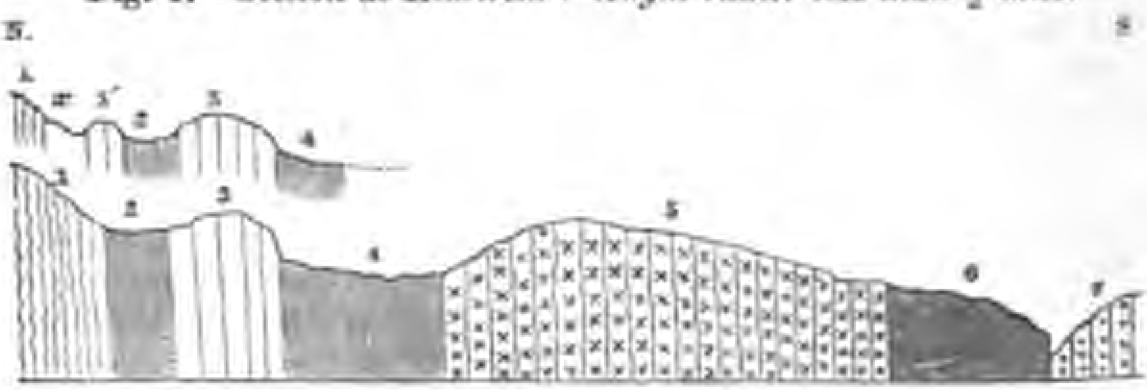
[1] The measurements in this paper were taken with a pocket-aneroid, and therefore they are only approximate. I think the error in reading would be less than 10 feet, but the instrumental error is uncertain, as it varies from day to day.

[2] I employ the term 'phyllite' for a slaty rock in which an unusually large amount of a minute secondary mica has been developed, which gives a peculiar 'sheen' to the cleavage-surfaces, *i. e.* one step nearer a schist than a slate, but still a long way from the former.

project slightly on weathered surfaces, are interstratified with more argillaceous layers. On the southern side rauchwacke occurs in irregular patches of no great thickness, being apparently not always present. On the northern side of the belt the junction of the phyllite and gneiss is exposed, though it is not very clear, for it is much troubled by quartz-veins. So far as I could see, the phyllite became rather sandy for the last few inches, though it did not contain visible fragments, and the gneiss was exceptionally crushed. On the southern side 'sericite-gneiss' crops out, and can be certainly identified within a short distance of the phyllite. It is possible that here also the junction is exposed, but in this place the rocks are so much crushed that I refrain from expressing a positive opinion. In this section I could find no trace whatever of the Altkirche marble, for even the most crystalline seams do not resemble it, but they reminded me rather of the matrix in some of the Jurassic *knotenschiefer* of the Nufenen Pass, etc.[1]

(b) *Sections on the lower slopes of the Oberalp.*—Some of these were described in my last paper, but, as I carefully re-examined the whole slope between the northern gneiss and the marble, clearing up some minor details and making one important discovery, I shall venture to describe it rather fully, though this involves a certain amount of repetition. Time will be saved by regarding this section, or rather group of sections, as a whole, and commencing the description at the back of the old church, some 40 or 50 feet above the high road of the St. Gothard (fig. 1). On the northern side is

Fig. 1.—*Section at Altkirche: length rather less than ½ mile.*



1 = Micaceous gneiss.
2 = Phyllite (Jurassic ?).
3 = Marble.
3' = Second mass of marble.
4 = Phyllite, etc. (Jurassic).
5 = 'Sericite-gneiss.'
6 = Phyllite (Carboniferous).
7 = Hospenthal schists.
x = Covered ground.

the gneiss, as usual, which runs up the steep mountain-slope, often terminating in a low crag, overlooking a slight depression. The latter is occupied, as already stated, by a dark phyllite, which can be seen cropping out within a few feet of the gneiss: the cleavage, which is nearly vertical, striking a little E. of N.E. The depression

[1] Confirmed by examination of one of the most crystalline-looking pieces under the microscope. Fragments occur with traces of organic structure, probably crinoidal.

is bounded on the southern side by a low mound-like shoulder, which also runs up the mountain, and can be readily traced for a considerable distance. On the northern slope of this shoulder the phyllite extends nearly to the flattened summit[1]; then, after about 3 yards of covered ground, comes a small outcrop of a fissile grey-coloured marble (?), followed, after about a yard, by another small outcrop of darker rock, which appears to me on the whole to present most resemblance to a variety of the marble very much crushed.[2]

In the next 4 or 5 yards are outcrops of a rather micaceous rock, very fissile and rotten, which I consider to be most probably also a crushed and much decomposed variety of the marble. To it succeeds an outcrop of a rock generally similar, but less fissile, and about 2 yards from that is an outcrop of a rock distinctly crystalline, at first rather micaceous, afterwards quartzose. Rocks of a like character, but rather more calcareous, can be traced for some little distance down the hill, roughly on the same strike. To the last-named outcrop follows the white marble which is quarried a little below the line of the section. On its southern side this mass forms a low cliff[3] overlooking a depression occupied by Jurassic rocks.

I must refer once more to the marble of this quarry. The lower and larger opening is 10 or 11 yards wide, across the strike; the excavation apparently being limited on both sides by a less pure[4] and more rotten condition of the rock. The quarried marble is very crystalline and occasionally is distinctly banded with seams of mica, when it resembles locally some of the calc-mica-schist which in other districts of the Alps forms part of the group of crystalline schists. The rock has a 'slabby' structure parallel to the seams of mica, and the surface of the slabs is 'fluted.' These structures and the general aspect of the marble produce the impression that when it was subjected to pressure it had already become a crystalline rock, and this impression is confirmed by the examination of several microscopic sections. As described in my last paper,[5] we can trace this shoulder of marble for a considerable distance up the steep mountain-side, but the section to which I must draw particular attention occurs about 250 feet above the high road.[6] Starting northward from this shoulder of marble, already mentioned, we cross, for about 40 yards (estimate), a turf slope, on which chips of phyllite abound, together with (apparently) small outcrops of the same.[7] Then we come to a

[1] I omitted to enter in my notes the distance of this from the northern gneiss, but I think the breadth of the phyllite outcrop cannot exceed 35 yards.

[2] The condition of both these rocks makes it impossible to speak positively as to their nature. Here No. 3 of the remarks made in the Introduction (p. 286) must be remembered.

[3] I halted here, because the grass was not yet mown on the ground below, and the age of this part of the section is not disputed.

[4] It contains a fair amount both of mica and of quartz.

[5] In which details of the microscopic structure of the marble are given, Quart. Journ. Geol. Soc. vol. xlvi. (1890) pp. 193–196.

[6] See the upper part of fig. 1, p. 288.

[7] I examined this slope most carefully, and was convinced that the phyllite is *in situ*.

second outcrop of marble, much smaller than the other one, forming a low craggy rib, which, however, can be followed for some distance up the hillside before it finally disappears. Lastly, after crossing another slope of turf, about 50 yards in width, we come to the gneiss already mentioned. Thus the upper section exhibits (as was the case in the St. Gothard tunnel) two masses of marble. Of these the one common to both sections is at a considerably greater distance from the gneiss in the upper than in the lower section. This obviously is suggestive of faulting.

Microscopic examination of the more micaceous and more quartzose rocks mentioned as occurring on the northern side of the marble shows them to possess the ordinary structure of a crystalline schist which has been subsequently somewhat modified by pressure. They consist of quartz, possibly some felspar, and mica (chiefly white); the former rock contains a few grains, rather rectangular in outline, of some rather decomposed aluminous silicate, and the mica is in somewhat larger plates and occurs in more definite films; the latter rock includes one or two zircons. Both are somewhat stained by a brownish or blackish substance (probably a hydrocarbon) which appears to be an infiltration. It must be remembered that the marble itself becomes not only micaceous, but also quartzose, the latter mineral sometimes dominating over the calcite, and the rock precisely resembling one of the more quartzose calc-mica-schists so common in the Alps. In other words, we have to deal, in this particular section, not with a single rock, but with a group of crystalline schists, in which a calc-schist or marble dominates, each presenting the aspect and structure which are elsewhere characteristic of crystalline schists (somewhat affected by pressure), and which I have never seen in the Mesozoic rocks of the Alps or of any other country.

Lastly, it must not be forgotten that on the southern side of the 'sericite-gneiss,' between it and the Hospenthal schists, is a belt of sedimentary rock consisting of a dark phyllite, with some bands of coarser material, which, on the Swiss Geological Survey map, is referred to the Carboniferous System. The 'sericite-gneiss' is most probably a modified granite, but whatever be its age (and this can hardly be post-Jurassic), a study of these sections alone is enough to show that the collocation of the various masses between the micaceous gneiss on the north and the Hospenthal schists on the south cannot be explained by a simple folding.

The St. Gothard tunnel, according to the map in Baedeker's Guide, passes beneath the meadows slightly to the *west* of the lower of these two sections at Altkirche. Since my return I have again examined the series of specimens from that tunnel which are preserved in the British Museum.[1] They exhibit the following succession, going southwards:—(1) Gneiss; (2) phyllite; (3) marble or calc-schist;

[1] I have to express my sincere thanks for the facilities afforded me by Mr. L. Fletcher, the Keeper of the Department of Mineralogy, and for the help of Mr. G. H. Prior, F.G.S.

(4) phyllite; (5) marble or calc-schist (this, I believe, corresponds with the mass which is quarried behind the church); (6) limestone (?) and schistose quartzite (examination of the hand-specimens does not enable me to decide whether these belong to the crystalline group or to the slaty sedimentaries); (7) gneiss; (8) limestones with phyllites—Jurassic; (9) soft, whitish calcareous rock, possibly rauchwacke; (10) gneiss; (11) phyllite, which alternates with gneiss or crushed crystalline schists, over about 520 metres (the latter dominating), after which the crystalline series becomes continuous and bears a general resemblance to that crossed on the ascent from Hospenthal to the St. Gothard. The northern part of this section would correspond with the upper section seen at Altkirche, if we may suppose the phyllite (2) to underlie the turf between the outcrops of the northern gneiss and the first rib of marble, which is not improbable. Of (7), which is labelled and appears to be a gneiss, I have not seen any sign at the surface. The limestones with phyllites (8) no doubt belong to the southern part of the Jurassic band. The remainder of the section from (10) onwards, which I have not quoted in detail, corresponds with the sericite-gneiss, the dark phyllite or schistose slate, and the Hospenthal schists (which appear to be more gneissose than they are about Hospenthal).[1] But this alternation of phyllites and crystalline rocks, so far as I have seen, is not visible on the surface. Thus the tunnel-section confirms the observed differences between the sections at Altkirche, and indicates a still more frequent intercalation of slightly modified sedimentaries with crushed crystallines than is shown at the surface. Also it exhibits, *west* of the lower section at Altkirche, a repetition of the marble, which is seen east of it at the surface. This strange variation in the number of times that the marble occurs is favourable to the hypothesis that the apparent interstratification of the crystalline and non-crystalline groups is the result of thrust-faulting, such as has been described by the members of the Geological Survey in the North-western Highlands. It must, however, be admitted that the 'slicing' demanded by this hypothesis is of a most remarkable kind, for the tunnel at Altkirche is at the very least more than 1000 feet below the surface, so that the 'wedges' of the older rocks driven through the newer must be unusually long and thin.

(c) *Section west of Altkirche.*—This is on the left bank of the Reuss, about a mile away from the last one. The fissile micaceous gneiss, which forms, as usual, the northern boundary of the sedimentary belt, crops out about 100 feet above the level meadows. Near the actual junction, the exact position of which is difficult to determine owing to the condition of the rocks and the presence of a large quartz-vein, begins a section, practically continuous, which can be followed down almost to the meadows. It exhibits a dark

[1] I have not examined a good seciton of them near Andermatt, where, so far as I remember, they are generally not well exposed.

lead-coloured, slaty or slabby, more or less calcareous rock,[1] such as is common elsewhere in the Alps among strata of Jurassic age; but not a trace is seen of the Altkirche marble, and there is no reason to suspect that it is concealed immediately beneath the water-meadows.

(d) *Section roughly north of Hospenthal.*—This is separated from the last by an interval of rather more than a mile. Here the gneiss (much crushed) ends at a height of about 750 feet above the river. Beneath the last outcrop of this rock the ground for about 50 or 60 feet vertical is covered; then begin a number of outcrops of dark, slabby, argillaceous limestone, like that just mentioned, followed at a considerable distance below, where the slope becomes less steep, by the Hospenthal schists. In one place I found projecting from the turf some bits of calcareous rock in a very 'slabby' condition, paler in colour and more crystalline in aspect than is usual with the indubitably Jurassic rock of the district. Whether it is *in situ* seemed doubtful, and a small moraine is close at hand. If, however, it be so, and is the marble (as I believe), then there is very little of it, and this is in a very crushed condition.

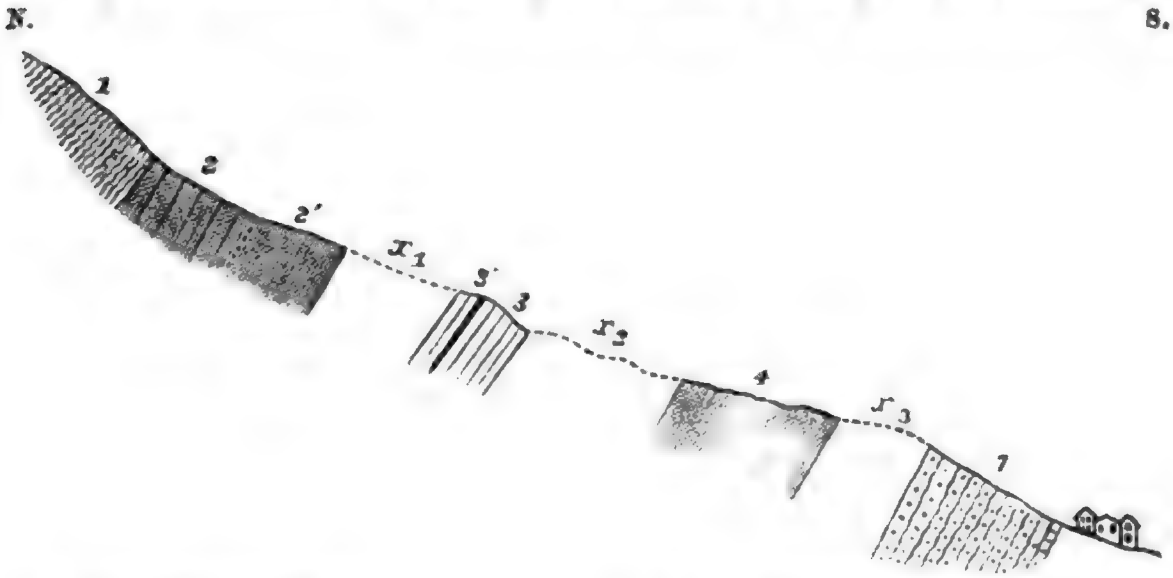
(e) *Section at Realp.*—This is obtained in a ravine on the same side of the valley, which descends near the lower end of the village, at a distance of about $3\frac{3}{4}$ miles from the last one. The rocks on the whole are well exposed; but to obtain a complete section we must cross the torrent, and there are even then three intervals where the ground is covered. The section on the opposite page (fig. 2) indicates the succession of the rocks, and does not require more than a few words of explanation. The marble (fairly well represented) is a very flaggy rock (3), which takes a yellow tinge in weathering. It corresponds under the microscope with the Altkirche marble, and the slice exhibits a very quartzose lamina. It is overlain by a darker variety more like an ordinary limestone (3'). The actual contact of the two cannot be examined, for they are always separated by at least a foot of accumulated débris, but the lower rock seems to become slightly darker in tint as it approaches the upper. Both rocks evidently have been much affected by pressure, and break into slabs which vary in thickness from $\frac{3}{4}$ inch downwards, sometimes being not more than $\frac{1}{4}$ inch thick, almost like slates.[2] The mass between these rocks and the gneiss above is the usual dark lead-coloured limestone, interbanded with dark phyllites; that between these and the Hospenthal schists below consists of

[1] The rock is quarried for a good part of the way. Specimens have been examined with the microscope: one is slightly more crystalline than usual (it was selected for this reason) but is very different from the marble.

[2] The microscopic structure of this rock presents difficulties, which will be more fully considered in dealing with the sections on the Furka Pass. It may be a crushed and stained condition of the marble, but it may be only a rather exceptional variety of the Jurassic limestone, and one or two grains show a structure that is possibly of organic origin.

phyllites, sometimes calcareous. The vertical distance from the base of the gneiss to the road is about 550 feet.

Fig. 2.—*Section at the back of the village of Realp, in the ravine.*



1 = Micaceous gneiss.
2 = Dark limestone (70 feet), dipping 20° N.W.
2' = The same, with greyish phyllite (40 feet).
x_1 = Covered ground (about 60 feet).
3' = Thinly-bedded, dull-coloured limestone (?), 12 feet.
3 = Marble, 30 feet, dipping 40° N.W.
x_2 = Covered ground.
4 = Phyllite, etc., about 120 feet.
x_3 = Covered ground.
7 = Hospenthal schists.

(The measurements were made by Mr. J. Eccles, F.G.S.)

(f) *Section between the Galenstock and Tiefenbach Hotels.*—After Realp is left, the road to the Furka Pass ascends much more rapidly, at first over Hospenthal schists, but at a distance of rather more than 1¼ mile[1] it crosses obliquely the Jurassic belt. First comes a little rauchwacke, which appears to occur in interrupted patches; then rocks of the usual Jurassic type succeed, phyllites dominating in the lower part, with quartzose bands towards the base, and the dark lead-coloured limestone in the upper part. Beyond these comes a brownish schist, more like one of the Hospenthal group than the ordinary gneiss, which, however, is presently cut by the road. In this section, which is generally very well exposed, I did not see any sign of the marble.

(g) *Sections at and near the summit of the Furka Pass.*—The road, after passing for a distance of rather less than 2 miles over gneisses and schists, into the details of which it is needless to enter, returns to the sedimentary rocks. These, however, can be seen running along the slopes below in a broad unbroken belt from the last-described section up to the top of the pass, which is still a good three quarters of a mile away.[2] We worked in 1891 across this

[1] This is as measured on the map, not as reached by path or road.
[2] The road to it keeps near the northern edge of the belt, once quitting it for a very short distance.

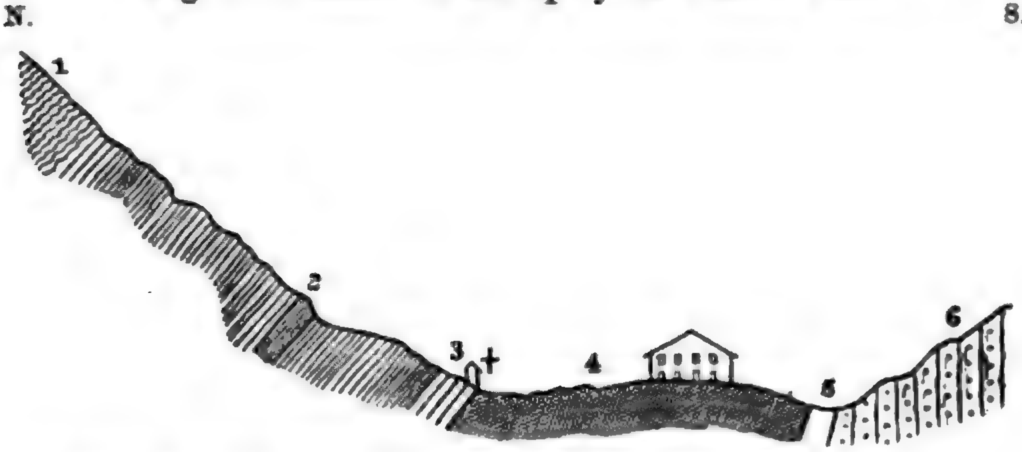
belt from the bed of the glen to the high road, which we reached no long distance on the eastern side of the 'col.' The stream, from which we started, was running over the Jurassic rocks. Ascending by the more eastern of two ravines (after examining the lower part of the other), we passed in succession over the following rocks:—(1) the usual dark slaty rock, with an occasional more arenaceous band, extending for a considerable distance up the slope; (2) a slabby whitish marble, which has a general resemblance to that at Altkirche; (3) a darkish subcrystalline and very slaty rock; (4) a rock more like 2, but less crystalline in aspect, more fissile, and greyer in colour; (5) a slaty, rather friable, lead-coloured limestone; (6) a darker and more slaty rock; (7) a more sandy variety of the same: (8) the usual rather crushed and micaceous gneiss. The outcrops 2, 3, and 4 seem to have a steeper dip than the rocks above and below, which obviously are Mesozoic, and their united thickness is considerably less than that of either group. On reaching the high road and going westwards we crossed back over 4, 3, and 2 in succession, the last running at the back of a small 'dépendance' of the Furka Hotel almost on the summit of the pass, and being quarried close to the former building.

The middle part of this section offers difficulties: 2 is the Altkirche rock, 3 hardly presents in the field or in hand-specimens the aspect of true crystalline limestone, but rather that of a slaty subcrystalline Jurassic rock. When examined under the microscope it is found to consist of grains of calcite, quartz, and pyrites, interspersed with black carbonaceous matter. Certain grains of the first exhibit a peculiar structure, developed by brown or black staining, which resembles that characteristic of echinoderms; these very probably are fragments of crinoids.[1] Those in the matrix generally are rather oval in form, about ·05 inch long, and may be compared (with it) to the matrix of the *knotenschiefer* in the Nufenen and Scopi districts. But some larger grains of calcite, which occur now singly, now in small clusters, including occasionally a grain of quartz, suggest by their outlines the possibility that they are in reality detritus from the marble. A second specimen, collected from the above-mentioned locality by the high road, showed a similar structure, contained fragments of organisms, suggested the possibility of detritus from the marble, and included quartz and a little felspar apparently of detrital origin, the latter having been somewhat enlarged subsequently. This rock not improbably corresponds with No. 3' of the Realp section. But No. 4 of the Furka section seems to be a true marble, so that, if our identification be correct, we have here, as in the neighbourhood of Altkirche, not only the marble thrust through the Jurassic rocks, but also a small portion of the latter nipped between wedges of the former.

[1] As I was distrustful of my own experience, I submitted these slides to Dr. G. J. Hinde, who most kindly examined them, and informed me that he had no doubt of the organic (probably crinoidal) origin of some of the grains, and that possibly other organic fragments were present, but that concerning these it was difficult to

South of the high road the section at the top of the pass (see fig. 3) is clear enough, but to the north it is not so well exposed.

Fig. 3.—*Section at the top of the Furka Pass.*



1 = Micaceous gneiss.
2 = Dark limestone and phyllites.
3 = Marble.
4 = Dark phyllites, etc.
5 = Rauchwacke.
6 = Hospenthal schists.

The rough slopes are steep, the ground is often masked by débris, and in one or two places on the western side is occupied by small pools or mud. Commencing on the southern side of the 'col,' we find that the crags, which also rise steeply in this direction, consist of the 'Hospenthal schist,' and that, next to this rock, a little rauchwacke (apparently only a few feet thick) is exposed at the very lowest point in the gap. From this to the high road the rock, which may be traced past the hotel practically without a break, is a black satiny slate or phyllite of the ordinary type, though perhaps the brown sandy bands are less frequent than in some of the sections already described. On the northern side of the road we find the flaggy marble (2),[1] which can be traced for some distance westwards with more or less interruption, and is cut again, I believe, by the high road on this side of the summit.[2] It is difficult to say how far the grey limestone (3) and the second band of marble (4) can be traced in this direction. There seems to be room for them, and on the flatter part of the broken ground north of the high road I thought that I identified both; but the exposures are bad, and the rocks are much crushed, so that it would be necessary to plot the whole area on a large-scale map before one could be certain. There is, however, no doubt that the steeper and more northerly part of the

[1] This and the next two numbers apply to the description on p. 294. The flaggy marble is numbered 3 in the woodcut (fig. 3), and the others are not distinguished.

[2] In 1893 a change for the worse in the weather prevented me from completing my observations on the western side of the pass, while in 1891 we had ascended to the summit up the middle of the valley, viz. keeping to the south of the high road, and thus traversed Jurassic rocks. These were 'slaty dark lead-coloured limestones, darkish phyllites, and rather brown sandy rocks,' bordered in places on the south side by rauchwacke, beyond which rose the Hospenthal schists. In the Jurassic group we found more than once the belemnites, distorted by pressure, which have been so often described from the neighbourhood of the Furka Pass.

slope is formed of a dark lead-coloured limestone and a slaty rock or phyllite (as is shown in fig. 3), above which, at a height of some 200 feet above the pass, the gneiss, being as usual rather micaceous and crushed, makes its appearance.

The testimony of these sections and such evidence as can be obtained by a general inspection of the district appear to me to justify the following conclusions:—

(i) That the belt of rock, admittedly Mesozoic, varies considerably in breadth.

(ii) That the strata of which it consists are neither abnormal in character nor more metamorphosed than is usual in a disturbed region with rocks of this age in the Alps.

(iii) That the rauchwacke is the soft, dusty, yellowish limestone which is found at the base of the Mesozoic rocks in dozens of localities between the longitudes of Olivone and Visp[1] on both sides of the watershed of the Alps, and occurs, as is so often the case, in irregular interrupted patches.

(iv) That the Altkirche marble (including the more quartzose and micaceous varieties) occurs in a very uncertain fashion, sometimes twice, sometimes once, sometimes not at all, and its thickness is certainly variable.

(v) That in one or two sections it undoubtedly passes into more micaceous and more quartzose schists, which correspond in all their essential characters with members of the crystalline series[2] in other parts of the Alps.

(vi) That there is clear proof of the Altkirche rock having undergone, after it became a marble, much mechanical disturbance, apparently similar in amount to that which has affected the adjacent Jurassic limestones.

(vii) That there is nothing to suggest that the exceptional condition of the marble may be due to 'contact-metamorphism,' and that the rock is practically indistinguishable from micaceous marbles which, elsewhere in the Alps, pass into calc-mica- and other schists and form part of the crystalline series.

Thus it appears that the evidence before us does not give an absolute demonstration of the age of the Altkirche marble. I have failed to find, on the one hand, a clear transition from it to the Jurassic rock, on the other a distinct unconformity between them or indubitable fragments of the former in the latter. Facts may be quoted for and against either hypothesis. That which affirms the marble to form part of the same system as the Jurassic rocks seems at first sight the more simple and more accordant with the field evidence in any single section; but, if it be adopted, we must confess ourselves unable to support the interpretation by evidence from other

[1] I restrict myself to regions where I have myself examined it during the last ten years.

[2] Those which I have elsewhere called the 'upper schists.'

parts of the Alps, or to find a cause for the metamorphism, or to account for its capricious action. Instead of keeping to the realm of law we are driven into the realm of miracle. The other hypothesis, which affirms the Altkirche marble with its quartzose associates to be a portion of an old floor of crystalline rocks on which the Jurassic rocks were deposited, and of which in process of faulting wedge-like masses were subsequently thrust through the overlying later deposits, can be supported on the grounds indicated above, but is open to the objections that the general coincidence in strike between the marble and the Jurassic rocks is singular, and the depth to which this simulated interbedding of two masses of very different age extends, as proved by the tunnel-sections, is unusually great. Still, if any trust may be put in comparative petrology, as it may be called, the difficulties in the latter hypothesis are much the less serious.

III. The Val Canaria Section.

Though it appeared to me that Prof. Heim's objections to my interpretation of the section of the ravine in the Val Canaria had but little weight, I thought it well to take an opportunity of revising our work. Of its general accuracy I felt confident; still, as we had not been a second time over the ground, mistakes or omissions in points of detail were very possible. Indeed, I suspected a clerical error in an aneroid observation, for the thicknesses assigned to the upper rauchwacke and the schist did not agree with my general recollection,[1] while that of the lower rauchwacke was only an estimate. The following results are, I believe, fairly correct. The vertical height of the outcrop of the upper rauchwacke is about 520 feet, of the schist 250 feet, of the lower rauchwacke 400 feet. I can add little to the account of the schists already given, for unfortunately they were not nearly so well exposed as they had been in 1889. A huge mass had fallen from the crags of rauchwacke (upper) on the right bank of the ravine, and its bed was completely buried by débris for a considerable distance below. Still, I was able to investigate one or two details of some little importance, especially as to the relations of the rauchwacke and the schists. The junction of the upper mass of the former rock with the top of the latter is not easily determined with precision, for the rauchwacke at this part contains flakes of mica abundantly, is much smashed about, and is very fissile. The schist, seemingly a variety of the disthene-schists,[2] is twisted, quartz-veined, apparently includes little lenticles of the rauchwacke, and presents an aspect very suggestive of 'mylonitic' action, that is to say of the existence of thrust-planes. The junction of the schist with the lower mass of rauchwacke is not

[1] It was, however, the latter rather than the former which was in fault.

[2] I retain the name for reasons given in the last paper; but it must be remembered that disthene (or kyanite) is commonly only a microscopic constituent, and the rock is a rather soft and friable schist, chiefly consisting of two species of mica (see Quart. Journ. Geol. Soc. vol. xlvi. p. 227, for description).

very well exposed, but the former (here a calc-schist) is much crushed and quartz-veined.[1] Prof. Heim denies that the section affords any evidence of thrust-faulting. What constitutes evidence is a question on which different opinions may be entertained. I can only say that I have not often seen anything more suggestive of thrust-faulting than the condition of the rocks just at the junction of the schist and rauchwacke,[2] and in such matters I am by no means a novice.

Our section, made in 1889, exhibits *three* bands of black-garnet schist which differ in thickness. On this occasion I could find only two, one being buried beneath the débris. The higher was a little more than 60 feet (vertical) below the top of the mass of schists, the lower approximately 20 feet above the bottom.[3] A comparison of my notes made on the two occasions leads me to the conclusion that the missing band is the middle one in the published section.[4] If so, it is for those who advocate the hypothesis that the schists and rauchwacke form a simple trough of Mesozoic rocks to account for this difference in the distances of the black-garnet schist from the bottom of the said trough. In any case, how are we to explain the presence of *three* bands of that rock? There may be 'luck in odd numbers,' but they are out of place in a transverse section of a simple trough. Prof. Heim cannot appeal to a fault to remove the difficulty; for if once he lets a fault 'in at the door,' he will find that the Jurassic hypothesis 'flies out at the window.'

On this occasion I examined more minutely and for a greater distance the schists above the upper mass of rauchwacke. It is, however, needless to give all the details. A 'disthene-schist,' which differs so slightly from those in the group of schists below, that with a little more crushing it would be indistinguishable, occurs more than once, and, from about 30 feet vertically above the top of the rauchwacke, bands of it are associated with gneiss or mica-schist containing actinolite.[5] About 10 feet above the rauchwacke is a garnet-bearing schist which macroscopically reminds us of the black-garnet schist[6] already mentioned, though the garnets are red and the mica is much more 'silvery.' But in other localities I have

[1] This is within about a dozen feet of undoubted rauchwacke. So greatly are the rocks 'troubled' near the actual junction that it is difficult to determine whether a very small outcrop in the interval is crushed schist or crushed rauchwacke, but I think it is the former. The latter rock hereabouts contains very small bits of silvery schist with clastic mica-flakes, but no large fragments as it does at the top of the higher mass.

[2] As stated in my paper (Quart. Journ. Geol. Soc. vol. xlvi. p. 209), I do not consider this to be the only evidence of thrust-faulting.

[3] It was 230 feet from the top. The junction of the schist and lower rauchwacke, as said above, cannot be determined with absolute precision.

[4] *Op. supra cit.* p. 210, fig. 5.

[5] That is, with rocks of the type to which, for descriptive purposes, I have given the name of the 'Tremola schists.'

[6] *Op. cit.* p. 209. My observations on this occasion made me doubtful as to the existence of a fault between those rocks [illegible] the 'Tremola schists'—the uppermost one in fig. 6, *op. cit.* p. 210 [illegible] absence is immaterial to the main question.

seen the garnets in this rock distinctly red and the silvery mica exceptionally dominant. I postpone any further inferences from this Val Canaria section till I have described another district.

IV. Section South of the Val Bedretto.

The schists, of which the northern face of the range on the side of this valley, nearly as far as Faido, is composed, are mapped by Von Fritsch as part of the mass to which those of the Val Piora belong. In order to compare the two I went from Rodi Fiesso (3110 feet) to the neighbourhood of the Campolungo Pass (lying, roughly, S.S.E. of the lower end of the Lago di Ritom). From a short distance above that village the path, which ascends steeply to the Lago di Tremorgio (5997 feet), traverses schists like those of the Pian Alto,[1] having streaky bands of dark mica, with brownish, more quartzose seams and yellowish streaks of calcite or crystalline calcareous rock. After passing the lake, the path, which mounts the steep slopes on its right bank, crosses similar rocks; but I found fallen blocks of black-garnet schist and one or two small outcrops of it *in situ*: for instance, at about 700 feet above the level of the lake. At the top of these slopes (about 160 feet higher) we come to the 'Campolungo,' a grassy plain or hollow excavated in a mass of white dolomite. At its western end, below the actual Campolungo Pass (7595 feet), the dolomite exhibits a fold, extraordinary even for the Alps. As it crops out from the turf it assumes this shape——being flanked by the dark schists on the south and partly overlain by them on the north. But at the eastern end of the hollow, where the path to Faido (which I followed) crosses a high spur from the main range, the dolomite appears to be regularly interbedded with the schists.[2] North of the pass (7041 feet) (nameless on the map) the schist seems to rise from beneath the dolomite and forms a ridge in which the rocks obviously correspond with those traversed by the path below, in ascending from the Lago di Tremorgio; the culminating point on this ridge is about 400 feet higher than the pass. On the south side of the latter the dolomite becomes flaggy and micaceous for about a dozen or 14 feet, and then changes rather suddenly into a mass of schists which bear a general resemblance to the ordinary dark-mica schists of the Val Piora, and contain some seams of typical black-garnet schist. This 'dolomite' consists of a well-bedded group of strata, which vary slightly in character and probably in composition. Sometimes they are pure white, sometimes greyish, sometimes yellowish. Tremolite is often abundant, the crystals not seldom being over 2 inches in length, and fine masses can be readily picked up. The mineral appears to occur in rather irregular lenticular seams. I have recorded in my notebook full details of the section from the one

[1] *Op. cit.* pp. 199–203.

[2] The simplest explanation is that the flat curve of the dolomite becomes more pointed towards the east and is pushed over to the north, so the beds on this side (apparently below) are part of the mass which overlies it on the south.

mass of schist to the other, but think it needless to publish them. The point of main interest is this—that a group of stratified saccharoidal dolomites or marbles, very different in character from the rauchwacke, is associated here, apparently in due sequence, with schist indistinguishable from that in the Val Piora, and from some of that in the Val Canaria ravine. A similar dolomite or marble is interstratified in the Binnenthal with the dark-mica schists of that locality, in which also the black-garnet schist occurs, and all these rocks as a whole appear to me inseparable from the schists, generally calcareous and micaceous, which extend along the Pennine range far away to the west, by the districts of the Simplon, of Saas, and of Zermatt, not to mention places yet more distant.

From these and other investigations I draw the following conclusions and inferences:—

(i) That the dark-mica schist and the black-garnet schists (though the latter are less frequent and the minerals not quite so large) on the *south* side of the Val Bedretto cannot be distinguished from the rocks which bear those names on the *north* side of the same valley.

(ii) That in the one case they are associated with much saccharoidal dolomite or marble, in the other with calc-mica-schists and some bands of marble. Of these rocks also hand-specimens might be collected which very often would be indistinguishable.

(iii) That in the latter locality thin bands of disthene-schist (*i. e.* the two-mica-schist) also occur. These, however, I did not see in the Campolungo district, but they exist farther west on the Nufenenstock.[1]

(iv) Hence, if the schists north of the Val Bedretto (Val Canaria, Val Piora, etc.) are Jurassic rocks, so are those south of the same valley.

(v) But the group of schists, etc., south of the Val Bedretto can be traced westwards by the Nufenenstock and its vicinity to the Binnenthal. The dark-mica schists maintain the same general character; in the Nufenen district they are associated with black-garnet and so-called disthene-schists, in the neighbourhood of Binn with black-garnet schist and dolomitic marble. Hence these schists, etc., are also Jurassic.

(vi) But the rauchwacke (Triassic) in the Val Piora, Val Canaria, at Airolo, on the Nufenen Pass, and in the Binnenthal contains fragments of one or more members of this group of rocks, *e. g.* the dark-mica-, the disthene-, and the ordinary calc-mica-schists.[2]

(vii) Hence these Jurassic rocks are pre-Triassic, which, as Euclid says, is absurd.

[1] Quart. Journ. Geol. Soc. vol. xlix. (1893) p. 89. Very probably they do exist about Campolungo: I speak only of what I have myself seen.

[2] It is true that I have not yet succeeded in finding the black-garnet schist: but though to lay on the table a piece of rauchwacke containing this rock would be tempting as a *coup de théâtre*, I have never cared to spend much time or go out of my way to search for it. When of three kinds of rock, inseparably associated, two occur in a conglomerate or breccia, the positive argument resting

V. General Conclusions.

After studying the sections which have been described above, I spent some time in refreshing my memory of the 'Bündner schiefer,' especially in the defiles of the Via Mala and the Schyn, and in carefully examining, by no means for the first time, cases where Mesozoic limestone, yet farther to the east, is infolded in crystalline rocks. As the result, I repeat, if possible more emphatically than I have ever done before, that the Mesozoic phyllites, such as those in the Thusis district,[1] though bearing every indication of having been subjected to severe pressure, are readily distinguishable from the dark schists in the (upper) Crystalline group: the impure limestone and hard sandstones interstratified with the former, from the calc-mica-schists and the quartz-schists respectively, which form parts of the latter; and that the larger and purer masses of Mesozoic limestone or dolomite, when they occur, notwithstanding their general correspondence in chemical composition, are as different as they well can be from the marbles and dolomites which are associated with the above-named crystalline schists. The former, though often brecciated, sometimes almost shattered by pressure, are compact-looking, the latter saccharoidal. The only difficulty which arises in distinguishing the two groups of rocks is one merely local, when they happen to be exceptionally crushed *in situ*. The differences in microscopic structure are not less marked than in the macroscopic aspect.

Since my visit to the Alps in 1889 I have made two fairly extensive journeys in that chain (the former also in company with Mr. J. Eccles), in course of which I have 'sampled' the rocks bearing on these questions in many places, from the Val des Ormonds on the west to the Bernina Pass on the east, besides working at crystalline schists and slaty rocks in other countries. Observations in the field have been checked and tested by study with the microscope, using it not so much for micro-mineralogical as for 'pathological' purposes, with the result that I am more than ever convinced of the general accuracy of the conclusions which were expressed in my former paper 'On the Crystalline Schists and their Relation to the Mesozoic Rocks in the Lepontine Alps.'

Discussion.

Dr. J. W. Gregory remarked that the paper was a valuable contribution to an important controversy, as it contained three new

on their presence completely effaces the negative argument founded on the absence of the third, in any discussion as to the relative age of the two groups. Moreover, I have found fragments of black-garnet schist in a breccia at the base of the admittedly Jurassic rocks of the Alp Vitgira (*op. cit.* p. 235). Further examination enables me to speak yet more positively on this point than I did in 1890.

[1] I accept these as Mesozoic on Prof. Heim's authority, but have not myself attempted to fix their exact position. I am quite certain that they are much later than such rocks as the crystalline schists of the Pennine Alps.

sets of facts. The association of quartz-schists with the marble was a fact which told strongly against its Jurassic age, though the occurrence of a double series of the marbles and their repeated re-appearance to the west did look like interstratification. At Rocca Bianca in the Cottians there are saccharoidal limestones in comparatively unaltered phyllites, and calcareous masses appear to be liable to more thorough alteration than the argillaceous beds in which they may occur.

The AUTHOR said that he quite agreed with Dr. Gregory as to the comparative ease with which metamorphism took place in limestone. Still he thought it highly improbable that a true saccharoidal marble would be interstratified with a phyllite. He quoted cases to show how mistakes might arise, and said that, though his experience was very large, he had never seen an instance of such interstratification.

20. *The* GEOLOGY *of* MONTE CHABERTON. By A. M. DAVIES, Esq., B.Sc., F.G.S., and J. W. GREGORY, D.Sc., F.G.S. (Read May 9th, 1894.)

IN the study of the geology of the Cottian Alps the problem that has given rise to most difference of opinion is the age of the beds of serpentine and 'pietre verdi' which occur so abundantly among the schists of this district. Most geologists now admit them to be altered igneous rocks, though the theory of their being bedded sediments still lingers in Italy. As to their age, however, there is much greater uncertainty, so that in spite of all the work that had been done in the Cottians, when the subject was considered in 1890 in the description of the Variolitic Rocks of Mont Genèvre, it was only possible to conclude that "we must in fairness merely style them Post-Carboniferous until further evidence is forthcoming."[1] The locality that offered the best prospect of the solution of this question seemed to be on the flanks of Monte Chaberton, the great dolomite mass on the north side of the well-known pass of Mont Genèvre. Here a typical series of the intrusive rocks is associated with stratified beds containing three distinct sets of fossils, namely, those of the radiolarian phthanites of Cesana, the *Gyroporella* and other Triassic organisms of Clavières,[2] and those hitherto known only from some fallen boulders on the eastern talus-slopes of Chaberton. The age of the first and last of these was uncertain, and it was necessary to determine that of the last before any great advance could be made.

The fossils in the boulders had been found on two occasions; a few were collected by the members of the Société géologique de France, during its excursion to the mountain in 1861[3]; a larger and better series was obtained by Michelotti and is now in the Pisa Museum. These were described by him in 1877, and determined as of Silurian age[4]; the schists of the district were therefore assigned to the pre-Palæozoic. Neumayr re-examined Michelotti's specimens and identified them as Cretaceous.[5] The fossils, however, had never been found *in situ*, and the bearing of this change of view on the age of the main dolomite series was therefore very uncertain, nor could any positive objection be urged against either the views of Lory,[6] who included all the dolomite in his Liassic 'Calcaire du

[1] Cole & Gregory, Quart. Journ. Geol. Soc. vol. xlvi. (1890) p. 323.

[2] K. Diener, 'Der Gebirgsbau der Westalpen,' 1891, p. 18.

[3] 'Réunion extraordinaire à St. Jean de Maurienne,' Bull. Soc. géol. France, ser. 2, vol. xviii. (1861) p. 779.

[4] B. Gastaldi, 'Sui fossili del calcare dolomitico del Chaberton (Alpi Cozie) ... da G. Michelotti,' Atti R. Accad. Linc. ser. 2, vol. iii. Mem. (1876) ...-121, pls. i.-...

[5] ... Bittner, M. ... Fr. Teller, 'Ueberblick über die geologischen ...ältnisse eines ...ischen Küstenländer,' pt. iii. Denkschr. d. k. ...ad. Wissensch ... (1880) pp. 404-405.

[6] 'Stratigrap... Graies et Cottiennes,' Bull. Soc. géol. France, ...er. 3, vol. i. (... ... 'Description géologique du Dauphiné,' §§ 256 & 286, Bull. ... ser. ... (1864) pp. 14 & 72.

Briançonnais'; those of Zaccagna and Mattirolo,[1] who included them in the Permian and Trias; those of Gastaldi,[2] who regarded the Calcaire du Briançonnais as made up of Lias, Trias, and Carboniferous; or those of Kilian,[3] who regards this as composed of Trias and Lower, Middle, and Upper Jurassic.

One of us having failed on a previous occasion to find any trace of the limestones on the pass of Mont Genèvre, we commenced our search on the eastern cliffs of the mountain. We struck up the Grand Vallon, which cuts into the eastern face of Monte Chaberton; we climbed Mont Sisnières and thence up the north-eastern crest to the 2620-metre stone man. About this point we found numerous fossiliferous boulders, some of which also occur near the entrance to the Grand Vallon; the beds from which we thought it probable that these had fallen were inaccessible on this side. We therefore moved to Bourg Mont Genèvre and thence climbed Chaberton up the valley of the Gr. Baisses. We could find only Triassic limestones on the western slopes, but succeeded in discovering the coralline and shelly limestones *in situ* on the north side of the valley of R. Clos des Morts, just above a ruined sheepfold east of the Col de Chaberton. (See Map, p. 309.)

Figs. 1 & 2 illustrate the mode of occurrence of these limestones; they are much contorted, and have been let down by faults into the Triassic dolomites which are not especially crumpled. In places, as shown in fig. 2, the shelly limestones are much contorted, and overlie the uncontorted dolomites. There is therefore no doubt that the fossils do not belong to the dolomite series, but to one of later date, and that they have been preserved owing to their having been faulted down into, or across on to, the Trias. As some name for these beds is desirable, we propose to call them the 'Clos des Morts' Limestones.

We made a considerable collection of the shelly limestones, but the fossils are so fragmentary that Mr. R. B. Newton, F.G.S., of the Geological Department of the British Museum, is unable to determine any of them. We are none the less obliged to him for the care with which he has examined the specimens.

The corals, however, are more satisfactory: they all seem to belong to one species, which we regard as the same as that found by Michelotti in the Valle della Vermanagna, on the northern side of the Col di Tenda. This was identified as a *Cyathophyllum*.[4] Neumayr has pointed out the erroneous nature of this determination, and sections made from specimens collected by us show that it is one of the *Astræidæ* and belongs to the genus *Calamophyllia*. As one of us has had recent occasion (in connexion with the Indian

[1] 'Sulla geologia delle Alpi occidentali,' Boll. R. Comit. geol. Ital. vol. xviii. (1887) pl. xi.

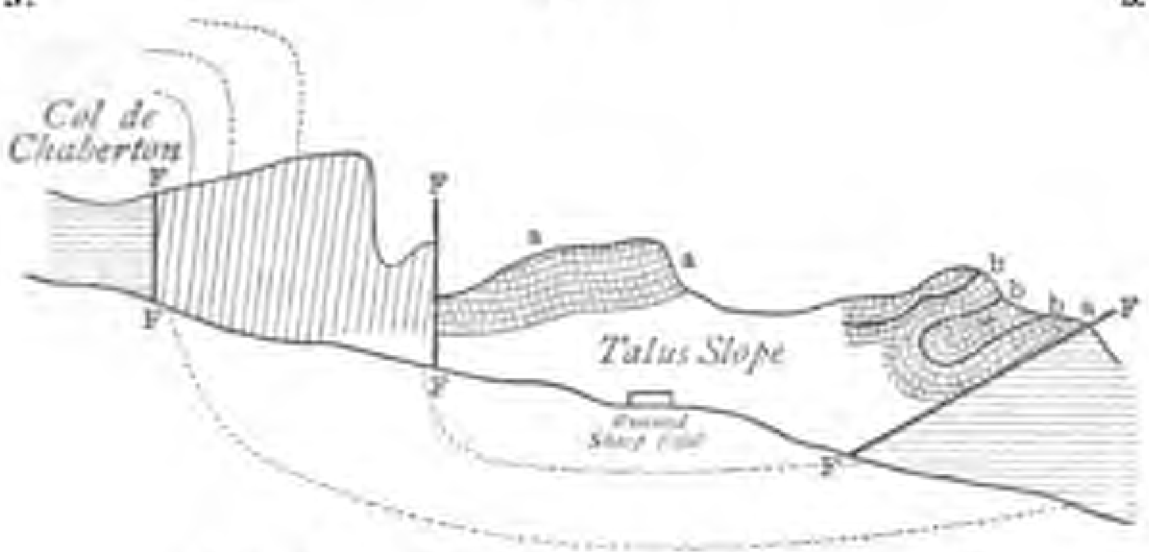
[2] 'Sui rilevamenti geologici fatti nelle Alpi piemontesi durante la campagna del 1877,' Atti R. Accad. Lincei. ser. 3, vol. ii. Mem. (1878) pt. ii. p. 959.

[3] 'Structure géologique des Chaînes alpines,' Bull. Soc. géol. France, ser. 3, vol. xix. (1891) p. 615.

[4] B. Gastaldi, 'Su alcuni fossili paleozoici delle Alpi marittime e dell' Apennino ligure studiati da G. Michelotti,' Atti R. Accad. Lincei, ser. 3, vol. i. Mem. (1877) pt. i. pp. 122–123 & pl. i.

Jurassic Corals) to revise the European *Calamophylliæ*, we have the less hesitation in referring the specimens to *Calamophyllia fenestrata*, Reuss.[1] The specimens agree in mode of growth, the thickness of the walls, the number of the septa, and the coarseness of the dentation. The prominence of the collerettes is well shown in one of

Fig. 1.



NORTH SIDE OF THE VALLEY OF R. CLOS DES MORTS.

Trias.
Cretaceous, a. *Shelly Limestone.* b. *Coral Reef.* } *Clos des Morts Limestones.*
F. *Faults.*

[This shows the Clos des Morts Limestones faulted into the Triassic dolomites. The direction of the lines in the dolomites indicates bedding.]

Fig. 2.—*Crumpled Clos des Morts Limestones carried by a thrust-plane on to uncontorted dolomite. (North side of the valley of R. Clos des Morts.)*

a = Black shale.
b–c = Triassic dolomite.
T = Thrust-plane.

[1] A. E. von Reuss, 'Beiträge zur Charakteristik der Kreideschichten in den Ostalp[illegible] [illegible]sonders im Gosauthale und am Wolfgangsee,' Denkschr. d. k. Ak[illegible] Wien, vol. vii. (1854) p. 105, pl. v. figs. 20, 21.

Michelotti's figures (*op. jam cit.* pl. i. fig. 2), and the septa in a weathered specimen collected by us (Brit. Mus. No. R. 2374) in the valley of the Clos des Morts.

Calamophyllia fenestrata, Reuss, is the typical species of the Gosau Beds, and it is therefore interesting to find that we are driven to the same conclusion by the study of the coral as that which Neumayr reached from the examination of Michelotti's gasteropoda. We are quite conscious that to maintain the existence of Cretaceous deposits in the Western Alps is a reactionary step, especially in view of Kilian's[1] recent refusal to admit any of the Monte Chaberton limestones as later than Jurassic, and Dr. Diener's[2] apparent retractation of this view in a recent letter; he had previously accepted it, and claimed that the fact "was the most remarkable phenomenon in the geological structure of the Western Alps."[3] Our profound faith in the late Melchior Neumayr's soundness of judgment and especial qualifications for expressing an opinion on this subject had been somewhat shaken by Kilian's doubts. The field evidence, however, has clearly shown that the coralline and shelly limestones are certainly post-Triassic; whereas Kilian's view seems to be based on the correlation of these beds with those near Oulx, which have yielded the *Myophoria* described by Portis.[4] The latter horizon is unquestionably rightly assigned by Portis to the Trias: the *Diplopora* (Schafh., non Young, *i.e.* alga, non bryozoon) associated with the *Myophoria* settle that point; but this bed is the representative of the *Gyroporella*-limestone at the base of the Chaberton series, and not of the limestones faulted down into the dolomites.

The question then arises, is this band of limestone the only representative of the Cretaceous in the Cottians? We think not, for the Vermanagna limestones must belong to the same horizon as those at Chaberton. A third representative is more doubtful, but judging from Kilian's[5] description of some limestones from Dorgentil, south of Moutiers, we should not be surprised if they also have gained their association with Jurassic deposits only by later dislocations.

We had thus determined the first of the two problems for which we had visited Monte Chaberton, for by proving that the coralline and shelly limestones are not part of the dolomite series, and are probably of Cretaceous age, a fairly complete time-scale has been established.

Let us next consider the relations of the associated igneous rocks to the various divisions of this time-scale.

The views held as to the nature and ages of these rocks are very varied. Those who regard them as metamorphosed sediments

[1] W. Kilian, 'Notes sur l'histoire et la structure géologique des Chaines alpines de la Maurienne, du Briançonnais et des Régions adjacentes,' Bull. Soc. géol. France, ser. 3, vol. xix. (1891) pp. 618–620.

[2] Quoted by Kilian, *ibid.* p. 620.

[3] K. Diener, 'Der Gebirgsbau der Westalpen,' p. 19.

[4] A. Portis, 'Nuove località fossilifere in Val di Susa,' Boll. R. Com. geol. Ital. vol. xx. (1889) p. 175.

[5] W. Kilian, 'Sur le Lias de la Savoie,' Bull. Soc. géol. France, ser. 3, vol. xix. (1890), Cpt. Rd. Séances, p. xxvi.

naturally class them as of the age of the rocks among which they occur; they therefore regard most of them as pre-Palæozoic, while the older Italian geologists, such as Gastaldi, and Gervais and Sterry Hunt, claimed them all as of this age. A later and smaller part of the series has been generally considered Tertiary, but Prof. Sacco's detailed work gives reason for showing that this later series may be Cretaceous. Those who regard these rocks as intrusive are less pronounced in their judgment as to the age, and though generally accepting the division into an ancient and recent series, they have even sometimes called this into question (Cole and Gregory, *op. cit.*).

The first point to be settled was whether the mass of serpentine cut through by the road at Clavières occurred in the calc-schists, in the dolomite, or between the two (as in Prof. Bonney's section [1]). The slopes at Clavières are too much covered by talus, and too near the Italian forts, to tempt one in that direction, so we struck round the Bois de Chaberton, hoping to find the same bed exposed in the Grand Vallon. (See Map, p. 309.) We soon came upon the serpentine, and determined two points about it:—

(1) That some tufas in the base of the Triassic limestones contain many fragments of the serpentine. Both the field evidence and examination of thin sections showed that the rock containing these is a true tufa and not a fault-breccia. This settles the pre-Triassic age of the serpentine;

(2) That the serpentine is intrusive into the calc-schists, as it here occurs in them, as it cuts across the strike of the schists, and as there is fairly well-marked contact-alteration on each side of the serpentine.

Elsewhere, however, on the mountain the Triassic dolomites are cut through by some sheets of schistose 'pietre verdi'; these may be seen in two places in the valley leading northward from the pass of Mont Genèvre to the Col des Trois Frères-Mineurs. The first is by a crag above and to the west of Gr. Baisses; the relations of the 'greenstone' to the basal quartzite of the Triassic series here is unquestionably that of an intrusive igneous rock. The second is beside the path leading to the Col de Chaberton, a little to the north of the 2145-metre point; here the evidence of intrusion is not so plain. Two other similar masses of the 'pietre verdi' occur on the northern arête of Chaberton between the summit and the Col de Chaberton. This is indisputable evidence that some of the igneous intrusions are post-Triassic.

It is advisable, therefore, to examine these rocks somewhat closely, in order to see whether it is possible to gain from them any guidance in determining the age of the intrusive rocks of the 'pietre verdi' series elsewhere in the Cottians. At Chaberton there are two main types: the serpentine which we now know to be pre-Triassic, but later than the 'schistes lustrés,' has been previously described [2]; but the later igneous rocks are so crushed as to be at present unrecognizable.

[1] 'Two Traverses, etc.,' Quart. Journ. Geol. Soc. vol. xlv. (1889) p. 80.
[2] Cole & Gregory, *ibid.* vol. xlvi. (1890) p. 306.

We have examined microscopically three specimens, two from the greenstone-schists a little to the north of the summit of Chaberton, and one from the dyke by the bed of a stream north of Gr. Baisses. The former consist mainly of lines of chlorite separated by bands of quartz, with a little authigenous white mica and some fragments of plagioclase; in one of the specimens there is an enormous amount of secondary quartz. The dyke by the stream consists also of much chlorite and quartz, with patches of a quartz-zoisite-calcite aggregate; there is, moreover, a good deal of titanoferrite passing into leucoxene. These rocks belong to the series which includes the appeninite, besimaudite, ovardite, etc., of some writers on the district. They are doubtless altered basic igneous rocks, probably crushed epidiorites. The only name, however, which we feel justified in attaching to them at present is that of quartz-chlorite schists or greenstone-schists.

We hope to consider the correlation of these two sets—the older Clavières serpentine and later chlorite-schists—with the 'pietre verdi' of other localities in the Cottians, in a more detailed account of these rocks and their distribution. But it may be worth mentioning here the probability that there is a third group of basic igneous rocks in the Cottians, which are of still later age. The gabbros, diabases, and porphyrites of Mont Genèvre, and of Rocciavré (north of the pass of Fenestrelle), may belong to this age; there is evidence suggesting that the gabbros of the former locality are intrusive through the serpentines at Punta Rascia.

The Earth-movements of Monte Chaberton.

No description of this mountain would be complete that omitted reference to the folds, faults, and thrust-planes that have combined to render its geology so complex and interesting. We should have wished to possess a large-scale map, and carefully work out the whole of its numerous faults. But the prolonged involuntary residence in the country that might have resulted from this detailed mapping would have been so inconvenient to both of us that we thought it advisable to forbear. A more precise survey must be left to an Italian geologist, until such a time as the nations of the Continent shall beat their bayonets into hammers; the numerous forts in the district will then afford superior accommodation to any that can now be got in the inns.

The movements may be divided into four main sets:

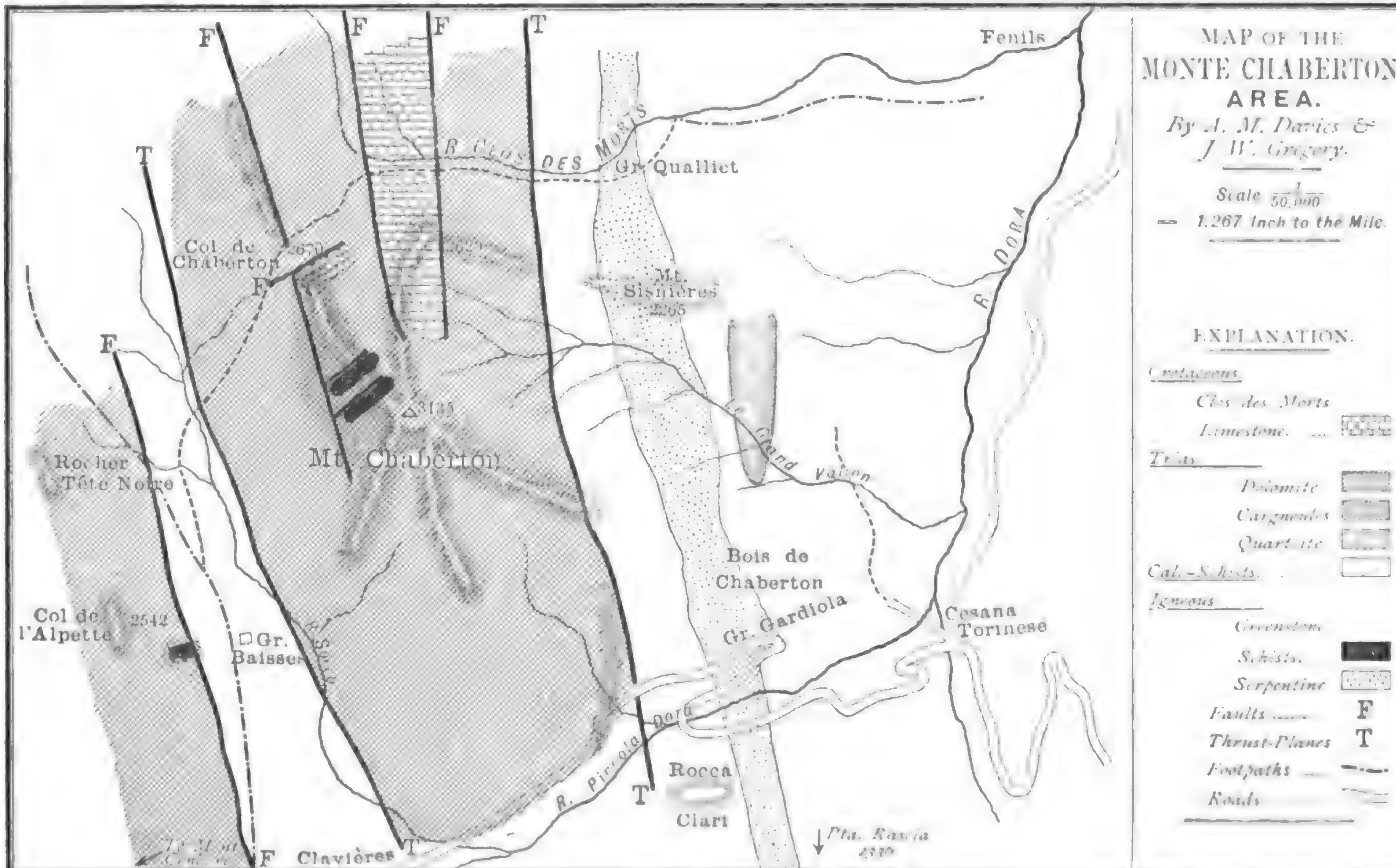
(1) A thrust-plane that has carried the Trias on to the calc-schists.

(2) A series of north-and-south faults that has troughed the Cretaceous limestones into the dolomites.

(3) Some east-and-west faults, to one of which the Col de Chaberton is due.

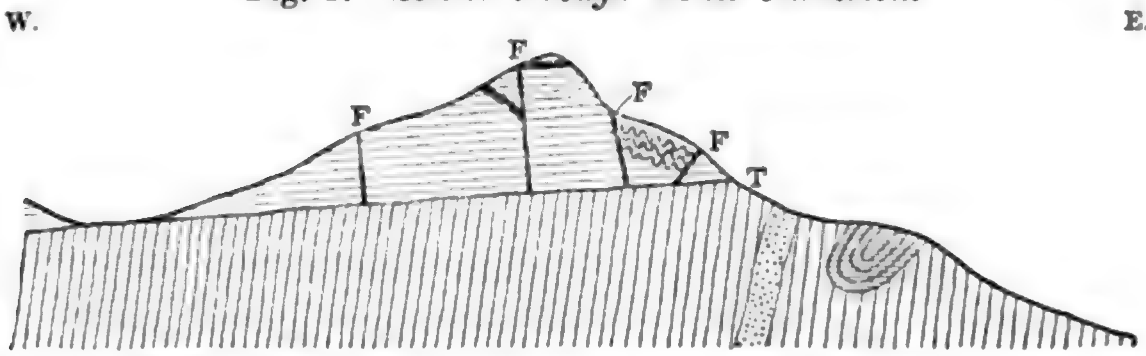
(4) A fold that has inverted the calc-schists on the eastern slope, and there caused an infold of the Trias.

The accompanying map and the section (fig. 3, p. 310) illustrate the general arrangement of these movements, but the exact order of


MAP OF THE
MONTE CHABERTON
AREA.
By A. M. Davies &
J. W. Gregory.
Scale 1/50,000
= 1.267 Inch to the Mile.
EXPLANATION.
Cretaceous.
Clos des Morts
Limestone.
Trias
Dolomite
Cargneules
Quartzite
Cal.-Schists.
Igneous
Greenstone
Schists.
Serpentine
Faults F
Thrust-Planes T
Footpaths
Roads
Fenils
R. Clos des Morts
Gr. Qualliet
Col de Chaberton
2670
Mt. Sisnières
2265
Mt. Chaberton
3135
Rocher Tête Noire
Col de l'Alpette
2542
Gr. Baisses
Bois de Chaberton
Gr. Gardiola
Grand Vallon
R. Dora
Cesana Torinese
R. Piccola Dora
Rocca Clari
Clavières
Pta. Rascia

their succession is doubtful. Numerous minor faults that do not affect the relations of the different beds to one another are omitted.

Fig. 3.—*Section through Monte Chaberton.*



Clos des Morts Limestones.......... *Cretaceous.*
Dolomites, Tufas, and Basal Quartzites. .... *Trias.*
Calc-Schists.......... *Pre-Carboniferous.*
Serpentine.......... *Pre-Triassic.*
Greenstone-Schists.......... *Post-Triassic.*
F....*Faults.* T....*Thrust-Plane.*

In conclusion we may summarize the results of the present paper as follows:—

(1) In the Cottian Alps there have been three distinct series of intrusions of basic rocks, the first pre-Triassic and post-*schistes lustrés*, the second post-Triassic and pre-Cretaceous, the third probably Lower Tertiary or Cretaceous.

(2) That the 'Calcaire du Briançonnais' consists of three distinct rocks:—the *cargneules* and dolomites of the Trias, the limestones of the Jurassic (which contain representatives, according to Kilian, of the lower, middle, and upper divisions of that system), and thirdly the shelly and coralline limestones which we call the Clos des Morts Limestones of the Cretaceous (possibly Turonian).

(3) That, in spite of the many doubts thrown upon the presence of Cretaceous beds in the Western Alps, representatives of such beds are known in at least two places in the Cottians.

(4) The identification of the common Gosau coral (*Calamophyllia fenestrata*, Reuss) in the Cottians.

Discussion.

Prof. Cole congratulated the Authors upon their survey of a difficult mountain-area. To him the most interesting rocks were the schistose dykes near the summit of Monte Chaberton, showing how much metamorphism might have taken place in the 'pietre verdi' generally since Triassic, and probably since Eocene times. He believed that the metamorphism produced in the Alps by Cainozoic earth-movements equalled anything that had gone on in earlier eras.

Dr. J. W. Gregory also spoke.

Mr. A. M. Davies, in reply, pointed out that the remarkable way in which the variolitic rocks of Mont Genèvre had escaped crushing was one of the facts that pointed to their very recent date.

21. Carrock Fell: *a* Study *in the* Variation *of* Igneous Rock-Masses.—Part I. The Gabbro.

By Alfred Harker, Esq., M.A., F.G.S., Fellow of St. John's College, Cambridge. (Read May 9th, 1894.)

[Plates XVI. & XVII.]

Contents.

1. Introduction.

During the last two years I have devoted some attention to the igneous rocks of Carrock Fell and the hills west of that well-known summit. Occurring in a somewhat critical situation on the border of the English Lake District, they were examined by Mr. J. E. Marr and myself, partly with reference to their bearing on the general geology of the district; but, apart from this, they offer in themselves some features which are of sufficient interest to be worthy of record. I have had the advantage of my colleague's co-operation, more especially in the field-work, and take this opportunity of acknowledging my indebtedness to him.

The earliest connected account of the Carrock Fell rocks was given by the late Mr. Clifton Ward[1] in 1876. He recognized three general types of igneous rocks in the district:—

(*a*) Spherulitic felsite of Carrock Fell and Great Lingy;
(*b*) Diorite (?) of Miton Hill and Round Knott;
(*c*) Hypersthenite of Mosedale Crags and Langdale.

He gave a brief account of their characters in the field and under the microscope, with chemical analyses of the first and last, and put forward a view of their mutual relations and mode of origin. In his opinion the several types pass into one another in the field, and he regarded them as produced by the metamorphism of part of the volcanic series, on the strike of which they occur.

Dr. C. O. Trechmann,[2] in 1882, pointed out that the dominant pyroxene in the so-called hypersthenite is not hypersthene, but diallage, and the rock would therefore be more correctly described as a gabbro.

Mr. J. J. H. Teall,[3] in 1885, briefly noticed the spherulitic felsite of Carrock Fell as a typical example of a granophyre in the sense

[1] Quart. Journ. Geol. Soc. vol. xxxii. (1876) pp. 16–27.
[2] Geol. Mag. 1882, pp. 210–212.
[3] *Ibid.* 1885, p. 109.

of Rosenbusch. Later he described both this rock and the gabbro (a quartz-bearing variety), stating that the one passes into the other by insensible gradations.[1]

In 1889 Mr. T. T. Groom[2] pointed out the occurrence on Carrock Fell of another type of rock, a tachylyte, in thin veins, cutting the gabbro, but considered to be connected with it. The same writer reasserted the existence of all transitional stages between the acid granophyre and the basic gabbro, and this passage seems to have been generally accepted.[3]

The references here given cover all the contributions of importance dealing with the subject of this paper since the early writings of Otley, Sedgwick, and others. Ward's work is embodied in the map of the Geological Survey.[4] He showed that rocks answering to the chief types which he recognized in Carrock Fell occur to the west as far as Roughten Gill. The sketch-map which accompanies the present paper (Pl. XVI.) differs from his as regards the boundaries of some of these intrusions; but in some parts, *e. g.* north and north-west of Carrock Fell itself, the want of exposures makes any precision impossible. This, however, does not affect the objects of the present study.

Carrock Fell itself is made up of an acid rock, which we may call 'granophyre,' since it usually shows very beautifully the granophyric structure of Rosenbusch. A similar rock is found beyond the concealed ground to the north-west, at Rae Crags; also at the head of Brandy Gill. From the latter place the rock is probably continuous, though never seen clearly *in situ*, to the exposures in the upper part of Roughten Gill and its feeders. Intrusions of granophyre, probably of the nature of minor offshoots, are also seen in Arm o' Grain and Thief Gills.

The other of the two chief rocks to be distinguished, which will be spoken of as the 'gabbro,' is seen south of Carrock Fell, as far as Mosedale village, and extends westward to Brandy Gill and Arm o' Grain, where the exposures in the gills show it alternating with the granophyre. A similar rock occurs in Roughten Gill and also higher up, in Thief Gills, where, however, it is much decomposed. The southern boundary of the main body of gabbro, from Mosedale village to Brandy Gill, is certainly, as surmised by Ward, a faulted one. The line between the gabbro and the granophyre runs from the upper part of Furthergill in a W.N.W. direction to a point about 200 yards east of Round Knott. Despite the alleged transition, which I shall discuss below, there is no difficulty in fixing this line sharply, wherever exposures occur; but it may be noted that a north-and-south traverse across Furthergill crosses alternations of the two rocks, which are naturally explained as due to offshoots of the newer one penetrating the older.

1 'British Petrography,' 1888, p. 178.
2 Quart. Journ. Geol. Soc. vol. xlv. (1889) pp. 298–304.
3 See, for example, Zirkel, 'Lehrbuch der Petrographie,' 2nd ed. 1893, p. 781.
4 England and Wales, 101 N.E. (New Series, 23). This map is dated 1890, but was not apparently issued to the public before 1893.

If the line between the main masses of gabbro and granophyre be prolonged westward past Round Knott, it divides the gabbro which ranges west of Iron Crags from the rock of Miton Hill, etc., Ward's dubious 'diorite.' To this title the rock has no claim, containing no hornblende except some of secondary formation, and it will here be named 'diabase.' For reasons which will appear in the following pages, I concur in regarding this as belonging to a separate intrusion, distinct from the gabbro to the south; but such a separation could not confidently be made on lithological grounds alone. In both rocks the texture is very variable. The rock on Miton Hill itself often assumes the coarsely crystalline characteristic of a gabbro, while many specimens from the crags in the gabbro-area would, if taken apart, be designated 'diabase.' The names will be employed, with this explanation, to emphasize the distinctness of the two intrusions and to mark their dominant characters. The diabase is cut off to the north by a fault seen in the southerly branch of Drygill, but it probably extends eastward under the much-obscured ground north of Carrock Fell.

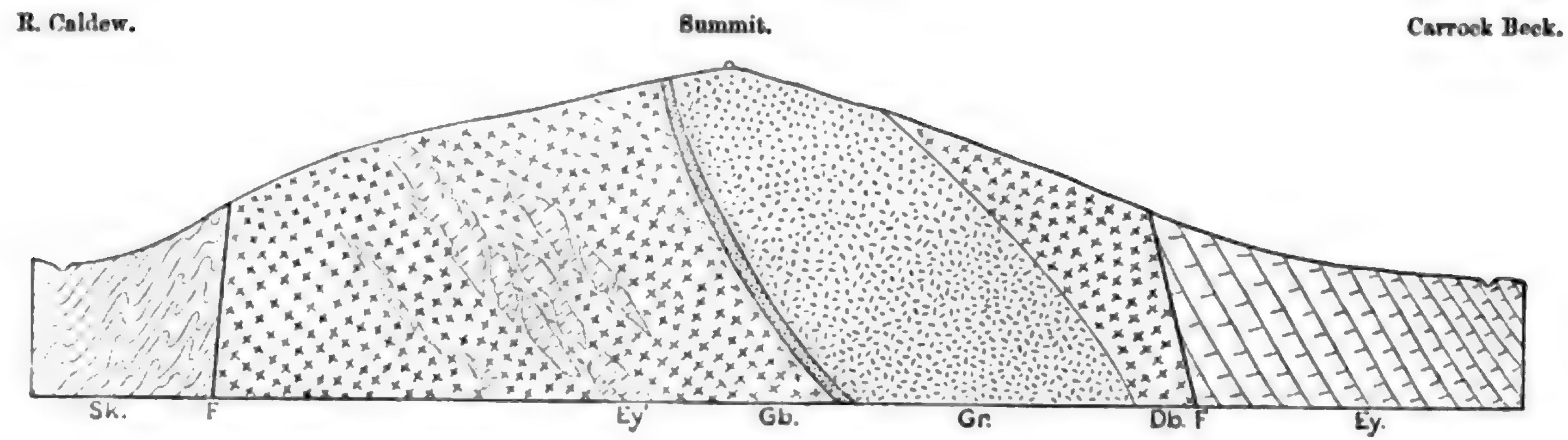
In addition to the above rocks, I hope to notice in a future communication a very interesting one which is seen at the junction of Brandy Gill with Grainsgill and in the adjacent hillsides. It is only incidentally mentioned by Ward as "a very quartzo-micaceous granite." It is, indeed, a 'greisen,'[1] and is so named on the Geological Survey map, where its boundary is indicated. This rock is, as will be shown, connected with the Skiddaw granite, and has probably no relation with the Carrock Fell intrusions.

Excluding the rock last mentioned, and taking the others as a whole, they are intruded, as is shown on the Survey map, among that part of the great Ordovician volcanic series which is conveniently known as the Eycott Hill group, a group consisting essentially of a succession of basic lavas. These lavas can be followed along a curved and broken line of strike from Eycott Hill to Carrock Fell, and they possess unique characteristics which place their identity beyond doubt. No junction of the intrusive rocks and these lavas is exposed along the northern line of boundary, although the Eycott rocks are seen at Clints Gill, etc., penetrated by small dykes and veins of granophyre. Along the southern boundary the gabbro is faulted against Skiddaw Slates. Mr. Ward states that the latter are "much altered," an expression which seems stronger than the appearances warrant. A certain degree of alteration may be granted, but it is doubtful how far this is connected with the gabbro. Tracing the Skiddaw Slates up the Caldew valley towards the granite and greisen, we find mere induration giving place to 'spotted' rocks, and these in turn to highly metamorphosed types ('mica-schists') to which Ward's description "much altered" well applies; but near Mosedale, where the effect of the gabbro can be tested apart from the disturbing element of the granitic intrusions, the alteration of the slate is not great. As regards the effect of the

[1] This rock was briefly noticed by me in 'The Naturalist' for 1889, p. 209.

Diagrammatic Section across Carrock Fell.

[Scale 3 inches = 1 mile.]



Gr. = Granophyre.
Db. = Diabase.
Gb. = Gabbro.
F = Faults.

Sk. = Skiddaw Slate.
Ey. = Eycott Volcanic Group.
Ey' = the same, highly metamorphosed.

fault, there must be a considerable downthrow to the north, but there is reason to believe that very little of the gabbro is lost by the break.

Both granophyre and gabbro form steep cliffs to the eastward, facing the alluvial flat of the Caldew, and they make no further appearance in that direction. This is probably due to their natural termination, and not to any fault. It is certain, at least, that the Eycott lavas come up to the intrusive masses on this side, for they are seen in the face of the gabbro cliff and on the heights above. The relations are not those of a simple junction of the intrusive rock with the lavas along a definite line. As one climbs up the cliff, *e. g.* at Snailshell Crag, sometimes gabbro, sometimes lava is seen, or the two together in intricate association, making it clear that large portions of lava have been enclosed by the molten gabbro. The same relations are shown at the top of the cliff, and the Eycott rocks occupy much of the ground along a W.N.W. line from here to Iron Crags, a distance of a mile or more. They are not continuous, but occur in large detached patches embedded in the gabbro and penetrated by countless veins of that rock. They give the idea of having been partly buoyed up by the molten gabbro-magma, which nevertheless welled up in every crack that was formed. A comparison of these phenomena with what is seen in the cliff near Snailshell Crag and Black Crag shows that the lavas must pass right into the gabbro-mass in the direction named, which is that of their strike. The remnants which are seen, embedded in gabbro, between Mosedale and Iron Crags are highly metamorphosed, but still easily recognized. The well-known and beautiful porphyritic lava (No. 4 of Ward's section [1]), the less markedly porphyritic lavas which succeeded it, and certain tuff-beds are clearly distinguished, and, what is more remarkable, they seem to occur in their proper order, and certainly follow their normal strike. It appears that the gabbro, forced in probably along the base of the Eycott group, has not only disturbed and lifted the lavas, but in some measure bodily engulfed considerable stretches of them. The Eycott group in this district has a very steep dip to N.N.E., and the mass of gabbro seems to have a similar inclination. Whether at the time of the injection the volcanic rocks lay more nearly horizontally is not evident from the mapping. I have found no lavas associated with the granophyre or the diabase. The remarkable patches of Eycott lavas enclosed in the gabbro did not escape the notice of Mr. Ward, who noted the occurrence of 'trap in hypersthenite' in the neighbourhood of Mosedale. I cannot, however, endorse his statement that the one rock passes into the other; the junction of the two is always of such a nature that both rocks can be clearly exhibited in one microscopical slice. The supposed transition was one of the grounds on which he based his suggestion of a metamorphic origin for the gabbro and its associated rocks.

The geological relations of the diabase need not be discussed at this point. I shall show reasons for believing that its intrusion

[1] Monthly Microsc. Journ. vol. xvii. (1877) p. 241.

followed that of the granophyre, while that of the gabbro preceded the acid intrusion. It may be remarked that numerous dykes or veins of granophyre similar to the rock of Carrock Fell occur in the gabbro to the south, but I have not found any of these in the area mapped as diabase. It can scarcely be doubted, however, that the three rocks belong to the same general period of igneous activity, and with them we may include in this statement the numerous basic dykes and veins, of which Mr. Groom's rock is one. These dykes were injected after all the larger igneous masses, for they are found cutting gabbro, granophyre, and diabase alike. The geological age of this complex of igneous rocks is a question which may be deferred for the present.

The greisen of Grainsgill is probably quite distinct from the preceding rocks. It must be referred, with the more normal type of the Skiddaw granite, to a late phase of the great post-Silurian disturbances. It is intrusive in Skiddaw Slates, and produces in them an extraordinary degree of metamorphism.

In the present communication the gabbro alone will be treated in detail, the granophyre, the dykes of Carrock Fell, and the greisen of Grainsgill being reserved for further treatment.

2. Mineralogical Characters of the Gabbro.

Before describing the remarkable variations of the gabbro in different localities it will be convenient to mention the minerals which compose the rocks. A triclinic felspar and a monoclinic pyroxene are essential to all the varieties, though their relative proportions may vary considerably. Quartz and iron ores become prominent constituents in the more acid and the more basic types respectively. Besides these, there are accessory and exceptional minerals and those of secondary origin.

The felspar occurs for the most part in idiomorphic crystals, which, in fresh specimens, are quite clear. They always show albite-lamellation, and usually Carlsbad twinning in addition, while pericline-lamellæ occasionally come in somewhat capriciously in portions of the crystals. The albite-twinning is sometimes inconstant or interrupted, but there is nothing to prove decisively that it is in general of secondary origin, although secondary lamellations, both albite and pericline, are found locally; see Pl. XVII. fig. 2. Sections perpendicular to the lamellæ give extinction-angles up to about 32°, indicating a basic variety of labradorite. The specific gravity is a little under 2·69. It is a point of some theoretical importance that the same variety of felspar is found in specimens of the gabbro differing widely in chemical composition. Only in some of the most highly basic rocks does the felspar sometimes show larger extinction-angles, indicating an approach to anorthite. On the other hand, in some of the more acid quartz-bearing rocks the border of a crystal gives a very slightly lower extinction-angle than the main portion, indicating that the outer layers are a

little more acid. This zonary structure seems, among plutonic rocks, to be specially characteristic of those which, without being true acid rocks, have developed free silica as the last stage of consolidation. Rosenbusch has remarked the general absence of zonary structure in the felspars of ordinary gabbros.

The felspar is, as a rule, though not invariably, of earlier crystallization than the pyroxene, and thus, while the latter mineral never builds very characteristic ophitic plates, the structure of the rock approaches that of a diabase. In view, however, of its coarse texture and of the peculiarities of the pyroxenic constituent, I have preferred to retain the name 'gabbro' used by other writers.

The dominant pyroxene, as remarked by Dr. Trechmann, is certainly a monoclinic one. It rarely shows any crystal boundaries, but occurs in allotriomorphic plates and wedges. The colour is of the light greyish-brown tone so frequent in diallage and salite, and there is no sensible pleochroism. Besides the well-marked prismatic cleavage, there are occasional indications of others parallel to the orthopinacoid and clinopinacoid. Simple twinning on the usual law, parallel to the orthopinacoid, is not infrequent, but this rarely gives rise to repeated lamellation. The most conspicuous feature of the mineral is a very delicate lamellation parallel to the basal plane, often marked by a certain amount of 'schillerization.' In a clinopinacoidal section the structure makes an angle of about 75° with the cleavage-traces, and if the crystal be also twinned on the usual law a very characteristic 'herring-bone' appearance results. (See Pl. XVII. fig. 1.) This has been figured by Mr. Teall[1] from the Whin Sill, a rock having several special features in common with the Carrock Fell gabbros. The characters of our pyroxene thus connect it with salite rather than with diallage; but, as the analyses of the rocks show that the mineral is rich in alumina, I shall speak of it as augite.

The most usual secondary alteration of the augite is that which results in a rather fibrous hornblende of a pale yellowish-green tint. The change begins at the margin of a crystal, and spreads to the interior, the augite and hornblende always having the usual crystallographic relation to one another. The completed pseudomorph still shows the orthopinacoidal twinning and the basal striation with its incipient schiller-structure. Small patches of brown hornblende in the interior of the fresh pyroxene seem to represent an original intergrowth, but these are of quite exceptional occurrence. Brown biotite, apparently a highly ferriferous variety comparable with haughtonite, is a frequent accessory constituent of the gabbro, but seems to occur only in special circumstances, which will be noticed below.

Although the original identification of hypersthene seems to have been erroneous, it is probable that a subordinate rhombic pyroxene was originally present in parts of the gabbro. Such is the most likely interpretation of certain pale green, fibrous pseudomorphs seen

[1] Quart. Journ. Geol. Soc. vol. xl. (1884) p. 647, pl. xxix. fig. 2.

in some slides. These occur more plentifully in some intrusions near Haweswater, such as that which forms Walla Crag. Of olivine I have found no certain trace, even in the most highly basic variety of the gabbro. This mineral seems to be unknown in the Lake District, except in a few minor intrusions such as that of Little Knott.

The presence of quartz in the Carrock Fell gabbro has long been known. It occurs sometimes in interstitial grains, but more frequently as a constituent of micropegmatite filling the interspaces between the augite and felspar-crystals. The intergrown felspar is probably in part orthoclase, the analysis showing a certain amount of potash in the rocks. The micropegmatite is a prominent constituent in the most acid gabbro, and is tolerably plentiful in many examples in which the silica-percentage must be quite low, failing completely only in the very basic varieties. (See Pl. XVII. fig. 3.)

Apatite, in rather stout prisms, is capriciously distributed. In many slides it is wanting, but it occurs in both acid and basic varieties of the gabbro, and in the latter sometimes rather abundantly. Grains of sphene are seen in some slides, but their form and their association with the iron ores are such as to suggest a secondary origin for the mineral.

Opaque iron-ores are very sparingly present in the most acid variety of the rock, but become increasingly abundant in the more basic examples, and in some form a very important part of the mass. In one case nearly 25 per cent. of the finely powdered rock was extracted by a horseshoe magnet. These rocks, very rich in iron ores, strongly attract the magnetic needle, but they show no evident polarity and do not orient themselves when freely suspended. The iron ores are in the main among the earliest products of crystallization in the gabbro, but they do not, as a rule, show any perfection of crystal outline. Viewed in reflected light some of the crystal-grains show a black or bluish-black colour, while others have a tinge of grey. The former only are attacked by cold hydrochloric acid. It appears, therefore, that we have both magnetite and ilmenite present, and the chemical analyses given below confirm this conclusion. In some places a crystal-grain consists partly of one, partly of the other mineral, with crystal-faces common to the two and a dividing line like a twin-line parallel to a crystal-boundary. (See Pl. XVII. fig. 5.) This is an arrangement which does not seem to be common in other rocks. Further, there are not wanting here indications of a more minute intergrowth of the two iron-ore minerals, and the colour of some grains leaves doubt whether they should be referred to magnetite or ilmenite. It is worthy of notice, too, that apparently almost the whole of the iron ore in the rock is magnetic. More precise knowledge concerning 'titaniferous magnetite' and 'titanomagnetite' seems desirable.

Pyrites is only locally present in the very basic gabbros (Arm o' Grain, etc.).

3. Minor Textural and Mineralogical Variations.

The remarkable differences, apparent to the most casual observer, among specimens collected from the Carrock Fell gabbro area are due to the coexistence of different kinds of variation, which must be considered separately. I shall distinguish:—

(i) Minor variations in texture, and sometimes in mineralogical constitution, usually on a small scale, following certain directions of banding, or without any evident arrangement;
(ii) Wide variations in chemical composition, and consequently in mineralogical constitution, having a definite relation to the form of the intrusive mass as a whole;
(iii) Strictly local modifications, forming part of a reciprocal metamorphism between (*a*) gabbro and enclosed masses of lava, or (*b*) gabbro and granophyre.

These will not all be discussed at equal length. The first and second are jointly answerable for the great dissimilarity between specimens collected from different spots, and of these the second is of greater interest.

I have already alluded to the variability in texture of the gabbro. As seen in the field, the change from coarse to fine grain is often rather abrupt. Sometimes the two are associated in a quite irregular manner, or patches of coarser rock occur embedded in finer. Such contrasts are seen not only on a small scale, but also between adjacent portions of gabbro, perhaps 100 yards across. In other places rocks of different textures are associated in alternating thin layers, simulating stratification, and slight differences in durability produce a fluted aspect on a weathered face. Ward appealed to this peculiarity in support of his theory that the gabbro represents metamorphosed volcanic rocks, but such an idea is, for many reasons, quite untenable. The phenomenon, indeed, is a very common one, and must be familiar to most geologists who have studied gabbros or other basic rocks.[1] It presents a rather perplexing problem, and suggests that some factor not yet fully appreciated has had some determining influence on the crystallization of such rocks. The banded structure of rhyolites, where crystalline or spherulitic layers alternate with glassy, has been explained by Iddings[2] as depending upon the different proportions of water contained in different parts of the magma, which were drawn out in the direction of flow, but such an explanation could have no application in the present case. I shall give evidence to prove that the gabbro-magma had very little viscosity when it was intruded, and that diffusion was able to operate through it after the intrusion, so that the banded structure can scarcely be taken to

[1] For remarks on this point, see G. H. Williams on the gabbros of Maryland, Bull. 28 U.S. Geol. Surv. vol. iv. (1886) pp. 25, 26, and A. C. Lawson on the anorthosites and gabbros of Canada, Neues Jahrb. Beil. Bd. viii. (1893) pp. 448 *et seqq.* [See also the paper by Sir A. Geikie and Mr. Teall, which is to be published in the present volume, where additional references are given.]
[2] Amer. Journ. Sci. ser. 3, vol. xxxiii. (1887) pp. 43–45.

indicate lines of flow. This structure seems to be quite independent of the more general variation in the gabbro-mass as a whole, which I shall describe below. At several localities the banding was observed to dip steeply to N.N.E., which agrees with what seems from other evidence to be the lie of the intrusion as a whole. Near Round Knott, however, there are lower and undulating dips, often southerly. In most parts of the gabbro no banding is observable.

The finer-textured portions of the gabbro have in the field a generally darker look than the coarser parts, which seem more felspathic. This—a common observation in such rocks—is perhaps in part illusory. There are, however, considerable local variations in the mineralogical composition of the gabbro, which are possibly connected with the variations in texture. Thus, at a few spots the rock is very rich in augite, the lustrous surfaces of that mineral appearing in a hand-specimen to make up by far the greater part of the whole. At no great distance this variety may be found to give place to one in which felspar and magnetite are richly represented. Gabbros are well known to be peculiarly liable to such variability, which does not necessarily import any very great difference in chemical composition between the several varieties. The felspar and augite probably do not differ much in silica-percentage, while the iron which goes into the pyroxene in one case goes into the magnetite in the other, the chief differences being probably in the alumina and soda. However this may be, the essential differences which these irregular mineralogical variations denote are certainly far less than those to be discussed next, which have a definite arrangement and an important significance. An account of these wider and more general variations will show conclusively that the gabbro represents a single intrusion of igneous magma, which was all thoroughly fluid at one time; so that the abrupt local changes and banded structure cannot be explained as the results of successive interlacing injections.

4. Orderly Variation from Centre to Margin.

Apart, then, from minor local variations, we must remark that specimens of the gabbro from different localities show wide differences both chemically and in the relative proportions of their minerals; and a study of the rocks in the field soon shows that the more acid varieties occur in the central part of the mass, the more basic near the edge. Two chemical analyses from different localities are given below: besides these I have had several silica-percentages kindly determined for me by Messrs. W. A. Brend and E. H. Cunningham-Craig.[1] The highest silica-percentage is 59·46 for a rock taken near White Crags; the lowest is 32·50 for the northern margin of the mass as exposed in the upper part of Furthergill Sike. The other figures obtained accord very fairly with the localities of

[1] The determinations were made by Messrs. Brend and Cunningham-Craig in the laboratory of Sidney Sussex College, Cambridge. Since writing the above, I have received the results of others made by Messrs. Boyd, Fry, Gunnell, Guthrie, King, and Peatfield, at the Yorkshire College, Leeds: these I owe to the kindness of Dr. J. B. Cohen. The two sets of figures are distinguished

the specimens, on the law that the gabbro becomes more basic from centre to margin. The mineralogical constitution of the rocks varies accordingly. The more acid rocks, in the central part of the area, have plenty of micropegmatite and scarcely any iron ore, while in the more basic rocks of the margin quartz is wanting and iron ores are very abundant, amounting in the extreme case to nearly one-quarter of the whole rock.

A very little examination of the rocks in the field is enough to convince the observer that the relatively acid and the extremely basic varieties of gabbro represent modifications of one original magma; that these extremes graduate imperceptibly into one another through intermediate varieties; and that all the varieties are arranged with striking regularity in successive zones corresponding in general form to the boundary of the whole mass. In view, however, of the great difference between the extreme types (the silica-percentage diminishing by 27 in 400 yards) and of the important deductions to be drawn from the phenomena, it is desirable to present the evidence of the continuity of the whole mass in some precise form. To obtain a large number of chemical analyses was impracticable, and I have accordingly availed myself of the density of the rocks as a rough test of their relative basicity, or, more particularly, of their relative richness in the denser minerals. This of course agrees in a general sense with the silica-percentages, the less acid rocks being the heavier; but, judging from such data as we have, the agreement does not always hold very precisely. The figures for specific gravity are found to show a much more regular distribution than those for silica-percentage. The reason for this is easily seen: the most important respect in which the several specimens differ is in their content of iron oxides, and the best test

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below by the letters S and L, respectively. I give here those which relate to the gabbro, and with them the figures from Mr. Barrow's two analyses and from that by Mr. J. Hughes mentioned in Ward's paper.

(i) White Crags:
Silica 59·46 (S); sp. gr. 2·804.
(ii) White Crags (the locality may be some distance from the preceding):
Silica 59·656 (Hughes).
(iii) 350 yds. S. of White Crags, 120 yds. W.N.W. of sheepfold:
Silica 57·7 (S); sp. gr. 2·877.
(iv) By road-side, about 150 yds. N.N.W. of Chapel Stone:
Silica 53·50 (Barrow); sp. gr. 2·800.
(v) Same locality:
Silica 50·5 (L).
(vi) 600 yds. S.W. by S. of White Crags, 200 yds. E.S.E. of sheepfold:
Silica 50·22 (S); sp. gr. 2·939.
(vii) 120 yds. N. of summit of White Crags:
Silica 47·11 (S); sp. gr. 2·848.
(viii) Top of cliff above Mosedale, southern edge of gabbro:
Silica 44·14 (S); sp. gr. 3·103.
(ix) Gill $\frac{3}{8}$ mile N.W. of Swineside, southern edge of gabbro:
Silica 43·4 (L); sp. gr. 2·952.
(x) Lower part of Furthergill, northern edge of gabbro:
Silica 33·4 (L); sp. gr. 3·200.
(xi) Upper part of Furthergill, northern edge of gabbro:
Silica 32·50 (Barrow); sp. gr. 3·265.

of this, short of actual estimation of the iron, is the density of the rocks.

The specific gravities have been determined by the hydrostatic balance on specimens usually of more than 50 grams, and so large enough to eliminate small variations: the figures are all reduced to 4° C. The mean specific gravity of specimens from forty-two different localities in the gabbro area is 2·953, and the range of variation is about 20 per cent. of this mean, the extreme figures found being 2·679 and 3·265.

If we take a traverse from north to south across the gabbro, we find the specific gravity to decrease steadily until the central zone is passed, and then to increase steadily to the other border of the intrusion. Below are the figures for three parallel traverses across the eastern portion of the area, where exposures are most frequent. Each hiatus represents a place where the rocks are concealed:—

3·222	3·265	3·200
2·848	——	——
2·804	2·850	2·933
2·778	2·822	2·800
2·844	2·890	2·872
2·877	2·939	2·922
——	3·110	3·103

It will be seen that, without exception, the gabbro grows denser from centre to margin in both directions. The full significance of the figures, however, is seen only when they are laid down on a map. With a sufficiently large number of observations, it would be possible to connect points corresponding to equal specific gravities by lines like the contour-lines round a hill or the isobars round a cyclonic centre. I have not attempted to go so far as this, but I consider that the figures given are sufficient to establish the continuity of the whole mass and the distribution of the several types in roughly concentric zones becoming denser from the centre to the margin of the area. The accompanying map (Pl. XVI.) shows the approximate course of lines corresponding to specific gravities 2·85 and 2·95. These arbitrarily chosen limits divide the gabbro area into three parts:

(i) A central portion of specific gravity less than 2·85: here the rocks are relatively acid, and usually contain rather abundant quartz;

(ii) An intermediate zone of specific gravity 2·85 to 2·95: consisting of more normal gabbro, in which quartz is at most an accessory constituent;

(iii) A marginal zone of specific gravity above 2·95, and in the limit very much higher: the conspicuous feature here is the great abundance of the iron ores.

Without entering into further detail, it will be taken as proved that the various types are only parts of a single body of rock, which becomes progressively richer in iron oxides (and, as we shall see, in certain other constituents) from centre to margin, and that this change is most rapid as we approach the actual boundary of the

mass. In other words, there has been, from whatever cause, a *concentration* of the iron oxides and certain other constituents in the marginal portion of the mass.

Phenomena indicating a concentration of this kind have been recorded in numerous instances from different parts of the world. Prof. Vogt[1] has recently reviewed the literature of the subject and critically examined all the leading facts; so that it is not necessary here to enter upon so wide a field. The phenomena are characteristically found in basic and ultrabasic rocks, and in extreme cases have given rise to almost pure aggregates of iron ore of undoubtedly eruptive origin. Vogt distinguishes especially an 'oxidic' type of concentration, characterized by the secretion of titaniferous iron-oxides, and a 'sulphidic' type, characterized by nickeliferous iron-sulphides. At Carrock Fell we evidently have to do with the former type. According to Vogt the titaniferous iron-oxides tend to aggregate by preference in the central part of an eruptive mass, while the nickeliferous iron-sulphides concentrate in the marginal part. As regards the former, this generalization seems to go rather beyond the facts, and the case that I am describing is emphatically opposed to it. In some of the cases which Vogt notices of aggregates of iron ores in the heart of an eruptive mass, the aggregates evidently are abruptly bounded, and their secretion from the magma must have taken place before the intrusion, so that the original relations are lost. Where a perfectly graduated transition indicates a differentiation of the intruded magma *in situ*, the enrichment in iron oxides, etc., seems to be typically a marginal phenomenon.

I now proceed to examine more closely the variations in the chemical composition of the gabbro. My friend, Mr. G. Barrow, of the Geological Survey of Scotland, has had the kindness to make a complete analysis of one selected specimen and a partial analysis of another. The former is an example of the quartz-bearing gabbro, though not actually the most acid rock found. The latter is the densest and most basic specimen obtained, having an extraordinarily large proportion of iron ores.

	I.	II.
SiO_2	53·50	32·53
TiO_2	0·45	5·30
Al_2O_3	22·20	
Fe_2O_3	3·60	8·44
FeO	2·64	17·10
MnO	0·35	
MgO	2·00	7·92
CaO	9·45	
Na_2O	4·26	
K_2O	0·61	
Ignition	1·50	
	100·59	
Specific gravity	2·800	3·265

I. Quartz-gabbro, by roadside, 150 yards N.N.W. of Chapel Stone. (The lime is probably a little too high.)

II. Iron-ore gabbro, upper part of Furthergill Sike.

[1] Zeitschr. für prakt. Geol. vol. i. (1893) pp. 4–11, 125–143, 257–284.

One point brought out by these analyses is that the augite, and the uralitic hornblende derived from it, must be rich in alumina. Another point of interest is that the iron ore is in a high degree titaniferous. If from the second analysis we calculate the iron ores as magnetite and ilmenite, the percentages of these are found to be 12·24 and 9·93 respectively, the two together thus constituting 22·17 per cent. of the whole rock.

Looking simply at the bulk-analyses, we observe that while analysis II. shows more than four times as much iron oxides as I., and nearly four times as much magnesia, it shows about twelve times as much titanic acid. In other words, regarding the second rock as a basic modification of the first, the titanic acid is much more strongly concentrated in the basic *facies* than the iron-oxides are. This is in agreement with what is recorded in other districts, such as those of Ekersund and Taberg. Vogt[1] remarks as characteristic of this type of modification ('oxidic' secretion of iron ores) that there is never less titanic acid than that corresponding to the relation Ti : Fe = 1 : 10, and often considerably more. In our rock the ratio is 1 : 5·3. As regards the other constituents, which were roughly estimated for the second rock, though exact figures are not given, analysis II., as compared with I., shows, in addition to the great falling off in silica, a very considerable reduction in lime, and a certain diminution in the percentage of soda, while the potash disappears almost entirely. Phosphoric acid has not been estimated, but the microscope shows that apatite, which is scarcely to be found in most specimens of the more acid varieties of the gabbro, becomes locally abundant in the highly basic marginal rocks. In all these particulars, the variation observed here resembles that recorded by Vogt and others in other parts of the world.

The Carrock Fell gabbro illustrates, then, a clearly characterized type of continuous variation in a single intrusive mass of basic rock, the variation being related in a simple manner to the boundary of the mass. It cannot be doubted that all the varieties have been derived by the differentiation of a single magma after its intrusion, and that such differentiation consisted in a concentration of what we may call the more basic constituents of the magma in the marginal parts. The phenomena thus afford an opportunity of bringing to the test some of the ideas that have been put forward with reference to the probable causes of differentiation in rock-magmas, and this I shall briefly attempt to do.

5. Discussion of the Causes of such Variation.

Several possible causes of differentiation have been suggested, and one or other of them may have been the chief cause in particular instances. In the present case the circumstances enable us to eliminate at once some of these suggestions. It may be remarked first that the concentration of the basic constituents is found along both the northern and the southern margin of the mass. These

[1] Zeitschr. für prakt. Geol. vol. i. (1893) p. 10.

probably represent the upper and lower sides of the intrusion as originally consolidated, but, whether this be so or not, the bilateral symmetry proves that gravity has not been the determining factor. This disposes, for the case under consideration, of the idea of a fluid magma becoming richer—in its lower strata—in the denser constituents; and also of the notion of the earlier formed crystals of iron ores, etc., sinking in the still fluid magma. If these processes have operated at all, they have produced effects only quite subordinate to the general differentiation observed. Again, Vogt has suggested that any inequality in the distribution of iron compounds in a molten magma, once set up, might be augmented by magnetic attraction. This idea is propounded apparently with reference to a central rather than a marginal concentration of iron ores in a magma, and moreover it could not account for the observed concentration of other constituents, such as phosphoric acid. In view of the fact that natural magnetite loses its magnetic property completely when heated to 557° C., it does not seem likely that magnetic attractions can play any part in the equilibrium of a molten rock-magma, and I shall accordingly discard this suggestion.

The only possible causes of differentiation that remain in the case under consideration are those which depend on the difference of temperature between the central and marginal parts of the magma while still fluid or partly fluid; and the concentration of the iron, etc., towards what were the cooling surfaces of the mass seems to point directly to the influence of this factor. In what way this influence took effect is a question requiring some discussion.

Most writers who have speculated on the mode of origin of a heterogeneous rock-complex by differentiation of a magma originally of uniform composition, have based their conception of the nature of the magma on its analogy with an ordinary saline solution. Lagorio[1] apparently considers that one or more definite silicate-compounds ($R_2O\ 2SiO_2$, etc.), which he terms '*Normalglas*,' act as solvent for all the other constituents. It is not easy to reconcile this view with the existence of a very fairly constant order of crystallization for the several minerals. For instance, however little phosphoric acid and however much of the iron oxides a magma contains, apatite seems to crystallize out invariably before magnetite or iron-bearing silicates; and, in general, the order of crystallization depends little, if at all, upon the relative amounts of the several constituents contained in the magma. As an alternative to Lagorio's idea of a single general solvent, we might perhaps imagine that a constituent on the point of crystallizing out is then the dissolved substance, the remaining fluid magma as a whole being the solvent. Some such idea seems to be intended by some authors who have not very clearly defined their view of an igneous rock-magma as a solution.

Now, it follows from the theory of osmotic pressure that if different parts of a simple saline solution be at different temperatures, the concentration must also vary, and equilibrium will be established

[1] Tscherm. Min. u. Petr. Mitth. vol. viii. (1887) pp. 507, 508.

only when the concentration at every point is inversely proportional to the absolute temperature. Soret has demonstrated experimentally the greater concentration of the salt in the cooler part of the solution. This law, known as 'Soret's principle,' has been applied by Lagorio, Teall, Brögger, Vogt, Iddings, and others, to the case of an igneous rock-magma regarded as a solution. In particular, the relative richness of the marginal parts of an intrusive mass in the more basic minerals has been explained as due to the concentration of the less soluble constituents of the magma, while still fluid, in the cooler region.

On this point one or two remarks may be made. In the first place, the idea cannot be entertained at all in connexion with Lagorio's theory of a single general solvent. As Bäckström [1] has pointed out, differences of temperature could not, on that hypothesis, alter the *relative* concentration of different dissolved constituents. We are therefore driven to some less precise and more complex view of the nature of the 'solution' in a rock-magma. Supposing, however, that something analogous to Soret's principle still holds, we may enquire whether this is adequate to explain the degree of concentration actually observed in the case of the Carrock Fell gabbro. The precise law arrived at by van't Hoff, identical with the law for gases, states that, in the condition of equilibrium, the concentration of the dissolved substance varies inversely as the absolute temperature. Now, in our case, the amount of iron ores in the rocks at the margin of the mass is at least twenty-five times the amount in the rocks at the centre; but it is manifestly impossible that the absolute temperature of the magma at its centre could ever be twenty-five times, or even five times, that at its margin. The explanation is clearly insufficient to account for the facts.[2]

It must be understood that I speak here of differentiation effected *in situ* in a magma, which may fairly be assumed to have been of uniform composition when intruded into its surroundings. We are not, in this case, concerned with *successive* differentiations of magmas and partial magmas amidst new surroundings, as conceived by Iddings, or as described by Brögger. On any solution-hypothesis of rock-magmas, Soret's principle does not afford an explanation of the variations observed in the Carrock Fell gabbro. Further, I question how far that principle, which holds good for dilute solutions, can throw light on the physics of a rock-magma near the point of crystallization, which must be compared with a nearly saturated solution.

The phenomena of differentiation described by Prof. Brögger in the eruptive rocks of the Christiania basin, and especially in those of the Gran district,[3] differ in a fundamental respect from

[1] Journ. of Geol. vol. i. (1893) p. 774. The author, however, does not limit his criticism, as is here done, to this particular view of the solvent medium.

[2] This argument has been advanced by me in a brief note: Geol. Mag. 1893, pp. 546, 547.

[3] Quart. Journ. Geol. Soc. vol. l. (1894) pp. 15–37.

those described above at Carrock Fell. Brögger points out that in his area rocks genetically connected may differ widely in *mineralogical* as well as in chemical composition. Thus, in his olivine-gabbro-diabase, the ferromagnesian minerals are pyroxene, olivine, and biotite; in the camptonite, which is an offshoot of it, brown hornblende largely predominates. He justly concludes that differentiation has "taken place in a liquid magma, even before crystallization of any importance had begun." In the Carrock Fell gabbro the case is quite different. Here the different varieties of the rock consist invariably of the *same minerals*, only in different relative amounts.[1] I have already remarked that the felspar is of the same variety in almost the whole of the rocks examined. If the differentiation of the magma had been completed prior to any crystallization, we should expect different parts of the magma to have given birth to different varieties of felspar. The complete want of olivine, even in the ultrabasic varieties of the rock, is another fact that would be difficult to explain on the hypothesis that the magma was differentiated first and then crystallized; and indeed such a sequence of events seems to be quite inconsistent with the phenomena that I have described. On the other hand, to suppose that the differentiation was brought about by a migration of minerals already crystallized out would raise obvious difficulties. No cause can be imagined to produce such a movement of crystals to the margin of the reservoir. The only alternative is to suppose that the differentiation took place by diffusion in a fluid magma, but not as a process distinct from and quite anterior to crystallization. It was, as I believe, effected in a quasi-saturated magma concurrently with the crystallization of the earlier-formed minerals.

The remarks just made apply, as stated, to the particular case under discussion, but it seems probable that many of the examples of differentiation recorded by Vogt and others will fall under the same head. The characteristic of all is that the several constituents are *concentrated in a definite order, which is identical with the order in which they crystallize out from the magma* (Rosenbusch's "order of decreasing basicity"). The concentration is greatest for the minerals belonging to the earliest stage of crystallization, viz. apatite, ilmenite, magnetite, etc. The minerals of the second stage, the ferromagnesian silicates, are less strongly concentrated. In such cases, when differentiation apparently "has been determined by, and is dependent on, the laws of crystallization in a magma," it seems reasonable to seek the cause of differentiation in the crystallization itself.

The conditions introduced by this simple hypothesis have no analogy with those of a dilute solution; and, though we may conveniently employ the terminology of solutions in speaking of it, it does not follow that we need frame any precise theory of the nature of an igneous rock-magma. The process of differentiation is brought

[1] Quartz and orthoclase are wanting altogether in the most basic varieties, but these, being the very latest products of consolidation, do not enter into the argument.

at once under the perfectly general principle of the degradation of energy. In whatever form the elements of a given mineral exist in the fluid magma, it cannot be doubted that the crystallization of the mineral from the magma involves in every case a very considerable evolution of heat. Hence whatever promotes crystallization in the magma will tend to the most rapid degradation of energy. When crystallization has already begun in one region of the magma, this result will be attained by a determination of that constituent with which the fluid is most easily saturated to that region of the magma which is already on the point of saturation. The region of the magma which first becomes saturated with a certain constituent will therefore, as crystallization proceeds, have its saturation maintained by diffusion at the expense of the rest of the magma. It is evident that, as a perfectly fluid magma cools down, the point of saturation, say with apatite (or with phosphoric acid), will be reached first in the margin of the body of magma, that being the coolest region and also, if the Soret action has already set up heterogeneity, the region of greatest concentration of the substance in question in the fluid magma. Apatite begins to crystallize out at the cooling surface of the magma, and diffusion maintains the saturation and crystallization in this the coolest region. Ilmenite and magnetite follow, and in turn the ferromagnesian silicates. But there will evidently be a tendency towards restoring temperature-equilibrium between the margin and the interior, and, what is more important, with falling temperature and increasing acidity the residual magma becomes so viscous that diffusion is more and more checked, and finally ceases. Thus the concentration towards the cooling surface is strongest for the first-formed minerals, and continually feebler for those which follow, according to their order of succession.

It seems, then, that the intimate relation between the phenomena of concentration and of crystallization, which has been remarked by several writers, leads to a simple explanation of the concentration of certain constituents in the marginal parts of a rock-mass; and from this explanation the fact that the order of concentration of the several constituents is also the order of their crystallization follows as a necessary corollary. Further, there is here no narrow limitation of the possible degree of concentration, such as that which the law of osmotic pressure imposes upon the Soret action. There is no difficulty, for instance, in admitting that a pure aggregate of ilmenite may segregate from a rock-magma. According to 'Soret's principle,' this would imply an infinite degree of concentration, corresponding to absolute zero of temperature!

There is, however, one consideration that must not be passed over without notice. Bäckström[1] asserts that "a silicate magma during its period of crystallization is certainly too viscous to permit of any considerable diffusion." It does not appear on what evidence this statement rests. The petrographical features which most clearly point to high viscosity are connected especially with

[1] Journ. of Geol. vol. i. (1893) p. 773.

the later stages of consolidation in acid lavas: while the phenomena of differentiation are most strikingly exhibited in the earlier stages of consolidation of basic intrusive rocks. The best experimental results bearing on the question are those of Vogt,[1] obtained from artificial slags having the general composition of igneous rocks. Any differences that exist between the conditions in the artificial and the natural magmas will probably tend to lower the viscosity in the latter, which may be expected to contain a certain amount of water in all cases, and sometimes other fluxes ('agents minéralisateurs'). Vogt found viscosity to be in direct relation to acidity, the results differing widely for extreme cases. At the same moderate temperature-distance above their respective melting-points, strongly basic slags flow like water, while strongly acid ones are as stiff as tar. The 'melting-point' of a rock-magma is not a term of precision; but, so far as our knowledge goes, it seems highly probable that diffusion can proceed freely during the earliest stage of crystallization in a basic rock-magma, being, however, checked more and more as the temperature falls.

6. Some Deductions from the Phenomena.

I have dealt rather fully with the gradual variation of the gabbro from centre to margin, because the results, if they are considered to be established, bear upon theoretical questions which have lately attracted much attention. But these results also have very direct consequences for the particular area under discussion, leading to certain definite conclusions as to the geological relations of this gabbro intrusion, and enabling us to discard confidently certain suggestions that have been made under this head. Similar reasonings will be applicable to other masses of igneous rocks showing a like type of differentiation. The several points are sufficiently obvious to be treated summarily.

Firstly, then, the gabbro is a true igneous rock. The whole body of it was at one time fluid enough to admit of the freest movement among its parts, and that too *while all the surrounding rocks were cool.* This consideration, we think, is enough to dispose of the theory of Mr. Ward,[2] that the gabbro has been produced by extreme metamorphism of the volcanic rocks. Chemical and other facts equally militate against such a hypothesis.

Next, we see that the gabbro mass does not represent any portion of a duct of a volcano, but is an intrusion of laccolitic type. The magma was injected among cool rocks, and there consolidated. Had there been any prolonged flow of molten matter, the surrounding rocks must have become heated, and the mass that finally

[1] Zeitschr. für prakt. Geol. vol. i. (1893) p. 275.

[2] Ward quotes from Sedgwick a passage in the same general sense, though offered merely 'as a conjecture' (Third Letter to Wordsworth, 1842). J. G. Marshall maintained the Carrock Fell rocks, with all the chief igneous masses of the Lake District, to be of metamorphic origin (Report Brit. Assoc. 1858, Trans. Sect. p. 84.)

plugged the channel would have consolidated without the conditions necessary for the kind of differentiation described. Indeed we may take it as a general rule that the duct of a volcano is characterized by very considerable *everse*, but an absence of *inverse* metamorphism.[1] In the present case the form of the intrusive body and the manner in which the volcanic rocks follow their strike undisturbed through the heart of the gabbro also indicate unmistakably the nature of the intrusion.

Again, the alleged passage from the gabbro to the granophyre is seen to have no real existence, at least so far as concerns the phenomena in the former rock. That modification of the gabbro which in some petrographical features approaches the acid rock, forms the heart of the gabbro mass, while that in actual contact with the granophyre is of a highly basic variety. I propose to consider the question again from the side of the granophyre, but it is quite clear that the two rocks represent two distinct and successive intrusions. This is, of course, quite consistent with the possibility of the two magmas having been derived from different portions of one deep-seated reservoir.

Finally, I cannot accept Prof. Sollas's suggestion[2] that the micropegmatite of the quartz-gabbro is due to an injection of solid gabbro by the granophyre magma. There are certainly veins of granophyre penetrating the gabbro, and locally numerous, but these are never on the microscopic scale described by Prof. Sollas at Barnavarve, and the orderly disposition of the various types of gabbro in the Carrock Fell intrusion would be unintelligible on the injection hypothesis. I shall have to speak later of the possibility of intermediate rocks originating by the admixture of acid with basic, in a somewhat different manner, but I do not believe that the idea is capable of any very wide extension.

These conclusions seem to follow fairly from the phenomena of differentiation described, though they can be fortified by other considerations. I wish to point out, however, that these phenomena may sometimes lead to conclusions which could not otherwise be reached; so that a careful survey of an igneous mass by chemical tests, or simply by specific gravities, may give definite information regarding the field-geology of the district. Thus, the separation of the areas which we have distinguished as gabbro and diabase comes out distinctly in this way, the zone of basic rock which bounds the gabbro area on the side of the granophyre being evidently prolonged westward by Round Knott. When thus divided, the relative age of the two rocks can be decided. It might, of course, be conjectured plausibly that, since veins of granophyre are abundant in the gabbro and wanting in the diabase, the one rock is older and the other

[1] These terms, due to Morlot, besides having priority, seem to be more pointed and less clumsy than their equivalents 'exomorphic and endomorphic,' or 'exogenous and endogenous,' used by some German and French writers.

[2] Geol. Mag. 1893, pp. 551, 552. [Subsequently elaborated in Trans. Roy. Irish Acad. vol. xxx. (1894) pp. 477-512.]

newer than the acid intrusion [1]; but the way in which the gabbro is differentiated affords at least as strong an argument in the same direction. It is noteworthy that, so far as the few observations of specific gravity go, the diabase seems to be much more uniform than the gabbro, as if the requisite condition for differentiation, namely, cool encasing walls, had been wanting in the case of the later intrusion.

Again, if the basic margin may be taken as marking with tolerable uniformity the original boundary of the gabbro mass, its completeness or otherwise will give information with respect to subsequent accidents which may have affected it. The presence of a basic border on the south side of the intrusion may be taken as indicating that very little of the gabbro is lost in consequence of the bounding fault. On the northern boundary some irregularities occur which suggest that portions of the basic margin of the mass may have been carried away by the later intrusion of granophyre, and I shall have occasion later to notice phenomena in the latter rock which fully accord with this idea. Again, the narrowing of the outcrop of the more acid type of gabbro towards the east seems to point to a termination of the intrusive mass in that direction, so that no fault would be required to account for the non-appearance of the gabbro on the other side of the valley alluvium. As regards the westward termination of the intrusion, the country there is much concealed by peat-mosses, but the thoroughly basic character of the gabbro seen in Roughten Gill and in Brandy Gill [2] may perhaps point to a coming together of the northern and southern boundaries of the original intrusive body, which is broken into by considerable masses of granophyric rocks.

7. Reactions between Gabbro and Enclosed Masses of Lava.

There remain to be briefly noticed certain special modifications of the gabbro which are of an entirely different order from those described above, being local or 'contact'-phenomena. As already mentioned, some of these peculiarities are connected with the enclosed patches of volcanic rocks, others with the proximity of the large granophyre intrusion. Only the former will be treated at length in this place.

I have stated that the masses of basic lava enveloped by the gabbro are readily identified as members of the Eycott Hill group, the typical locality for which is less than 3 miles distant. The rocks are nevertheless very considerably metamorphosed, and the gabbro in their immediate vicinity shows certain signs of inverse metamorphism. The lavas as they occur at Eycott Hill were briefly described by Mr. Clifton Ward,[3] who gave chemical analyses

[1] I have found no actual exposure of the contact of granophyre and diabase *in situ*, but junction-specimens of the two rocks occur among the loose blocks to the north of Great Lingy, and in these the diabase takes on a very fine-grained texture.

[2] Specific gravities: Roughten Gill 3·113, Brandy Gill 3·065.

[3] Monthly Microsc. Journ. vol. xvii. (1877) pp. 239–246.

showing from 51·1 to 53·3 per cent. of silica. Prof. Bonney[1] pointed out the occurrence in these rocks of an altered rhombic pyroxene. Mr. Teall[2] has given an account of one of the most remarkable flows. The characteristic features are the occurrence of large porphyritic crystals of a lime-soda felspar, frequently rounded and having peculiar inclusions, and the abundance in the groundmass of magnetite and pseudomorphs after hypersthene. The metamorphosed lavas enclosed in the Carrock Fell gabbro have a fresh aspect and a high density, the specific gravities of the conspicuously porphyritic and the more compact types being 2·835 and 2·887, as compared with 2·754 and 2·744 at Eycott Hill. The groundmass has become darker and more lustrous, and the large felspars have a clearer appearance, though not otherwise altered to the eye. Under the microscope it is seen that these felspars have for the most part lost their conspicuous inclusions in the form of negative crystals, but the crystals usually retain their identity, and show their albite- and Carlsbad-twinning unaltered. Only occasionally have they been recrystallized into a new mosaic [1550] in the fashion that we have noticed in the basic lavas bordering the Shap granite. The serpentinous or bastite-pseudomorphs after hypersthene have been converted into a very pale, greenish amphibole of rather fibrous structure. Possibly some of this mineral may represent the original augite of the lava or its decomposition-products, but the metamorphosed examples sometimes contain fresh augite [1549, etc.]. The little twinned felspars of the groundmass resemble those of the unaltered rocks, except in a greater freshness and clearness, which could scarcely be interpreted as conclusive evidence of recrystallization, but they sometimes appear to fit together in the manner characteristic of metamorphosed rocks. The magnetite seems to be on the whole in better octahedra than in the unaltered lavas. But what points more unmistakably to some degree of recrystallization in the groundmass is the disappearance in the most altered rocks of the isotropic base.

So far I have noticed familiar, and not even extreme effects of thermal metamorphism in basic lavas.[3] There are, however, at the actual junction of the lava with the gabbro, phenomena more unusual, involving reciprocal modifications in the two rocks. I have said that the line of junction can be shown in a thin slice under the microscope, but it is often a curiously irregular line; and the plexus of small felspar-prisms, which constitutes a large part of the groundmass of the lava, has been, so to speak, 'teased out' at the edge, so that scattered prisms lie a little beyond what

[1] Geol. Mag. 1885, pp. 76-80.

[2] 'British Petrography' 1888, pp. 225–227. For a notice of the same lavas as seen at Melmerby, across the Eden valley, see Quart. Journ. Geol. Soc. vol. xlvii. (1891) p. 517.

[3] Some of the lavas, on the southern edge of the gabbro, show a different type of metamorphism, and especially the development of abundant red garnets. These phenomena, which are found in very many parts of the Lake District, have, I believe, no direct connexion with the gabbro intrusion, and they will not be further referred to in this place.

must be regarded as the true line of junction. These scattered prisms of plagioclase are embedded in a perfectly clear mosaic of moderately coarse texture, which seems to be in some cases of quartz, in others of felspar, mostly untwinned. The structure is thus that which G. H. Williams[1] has termed 'micropoikilitic.' The general appearance is as if the felspars had been set free, by what was originally the isotropic base of the lava becoming dissolved and absorbed into the gabbro-magma. The material thus taken up is doubtless represented in part by the brown mica which we find in the neighbouring gabbro, but the quartz and the (probably acid) felspar of the clear mosaic are perhaps to be referred to the same source. Mica is developed only exceptionally in the metamorphosed lava, and has somewhat different characters from that in the gabbro. Its pleochroism is from a rich brown to colourless, and there are intensely pleochroic haloes around certain inclusions too minute for identification [1549].

Certain narrow veins, conspicuous in hand-specimens, pass from the gabbro-junction into the lava, and contain especially idiomorphic brown hornblende moulded by quartz [1626]. Again the micropoikilitic areas may take on the form of little veins extending into the lava [1553], or these may anastomose and spread for a short distance from the junction. Indeed, the groundmass of the lava very near to the gabbro seems locally to be replaced by patches of clear quartz, etc., wedged in among the porphyritic felspars, the needles of apatite, and the pyroxenes or their representatives [1625, etc.]. Both pyroxene and magnetite seem in some places to have been absorbed.

It must be concluded from these phenomena that the gabbro-magma has to some extent corroded away and incorporated in itself the glassy base of the lava, and even in places some of its minerals, in the immediate neighbourhood of the junction. Nevertheless all the facts go to negative the idea that the lava has been to any important extent melted down by the gabbro-magma. The felspars have not apparently been dissolved at all. Even the little prisms remarked as occurring outside the line of junction show no rounding or diminution in size, and since they do not occur to any greater distance than a fraction of an inch, it seems that very little of the rock can have been removed. The blocks of lava, and the fragments into which they are divided by veins of gabbro, are sharply angular.

The same inference might be drawn from an examination of the gabbro near its junction with the lavas. The rock here, and for a few feet, always contains brown mica, a mineral foreign to the normal gabbro. The mica, indeed, occurs nowhere else in the mass, with an exception to be noted below. At one or two spots where the mineral was noticed no lava was actually exposed, but these places were on the line of strike of the Eycott group as seen not far away, and doubtless mark the position of concealed patches of lava.

[1] Journ. of Geol. vol. i. (1893) p. 176.

If it be granted that the mica in the gabbro is a phenomenon of inverse contact-metamorphism, due to the absorption of a certain portion of the enclosed lava by the gabbro-magma, an interesting conclusion follows. It is clear that if such absorption had taken place soon after the intrusion of the gabbro-magma, when that magma was fluid enough, as we have seen, to permit free diffusion throughout, the brown mica could not have been restricted, as it is, to the immediate neighbourhood of the lava. The action must therefore belong to a later stage, when the magma had attained a considerable degree of viscosity, and must be connected with the growing *acidity* of the magma in its central region due to concentration of the basic constituents in the marginal parts. In point of fact, it is in the quartz-bearing varieties of the gabbro that these phenomena of inverse metamorphism are observed.

8. Conclusion.

The last kind of modification of the gabbro to be noticed is seen near the northern edge of the mass, at Furthergill and westward. On comparing the dense iron-ore gabbros along this strip with those on the southern border of the mass, certain peculiarities are observed which can only be referred to the proximity of the large body of granophyre intruded at a later time, when the gabbro was solid.

Some of these peculiarities may be considered simply as phenomena of metamorphism produced by the heat of the later intrusion. Thus, instead of the usual uralitic alteration of the augite, we find that mineral passing in a capricious fashion into a compact brown hornblende, which probably indicates some absorption of iron oxide from the ilmenite. Granular sphene has arisen probably from reaction between the ilmenite and the felspar [1866]. The felspar is much broken up into secondary minerals, among which specks of a pale amphibole are conspicuous as well as chloritic substances. Pale fibrous amphibole sometimes forms a fringe in crystallographic relation with augite, but evidently occupying the place of felspar [1525]. There are large patches consisting essentially of matted tremolite-fibres, the origin of which is not clear. With this may be associated a little brown mica [1536], while small patches of this or of a deep brown hornblende have formed characteristically about some of the grains of iron ore. The various changes observed, or at least some of them, point to thermal metamorphism of the gabbro by the granophyre. (See also Pl. XVII. fig. 4, and explanation.)

The rocks showing the above features may be regarded as the margin of the gabbro proper. They are immediately succeeded by rocks of a very remarkable character, which form a zone running up Furthergill and onward nearly to Round Knott, dividing the gabbro from the granophyre. Along this zone the gabbro has been in great part actually re-fused, and has crystallized again as a rock of strikingly coarse texture, with large idiomorphic felspars and large well-built crystals of hornblende. The granophyre

magma, mingling with the fused ultrabasic gabbro, has given rise to abundant micropegmatite, the appearance of which in a rock so rich in iron ores is very remarkable.[1] Beyond this zone of rocks are others produced by the incorporation of molten ultrabasic gabbro into the granophyre magma, but these varieties and the general relations between the gabbro and the granophyre will be more properly discussed in connexion with the latter rock. It will be noticed that the production of chemically intermediate rocks at the junction of a basic and an acid rock, as here recognized, has no resemblance to the injection of solid gabbro by minute veins of granophyre, as described by Prof. Sollas; but phenomena comparable with those which he has described are also locally found. (See Pl. XVII. fig. 6, and explanation.)

The rocks distinguished at the outset as diabase will not be more fully described. Mineralogically they resemble the gabbro, and they reproduce in a less marked manner some of the same phenomena of variation. They have certain special points of interest, but not connected with the subject in hand. The present paper deals specially with the variations exhibited in the large gabbro intrusion. I hope on another occasion to show that the Carrock Fell granophyre also exhibits considerable variations, due to another cause, and that the Grainsgill greisen is the result of a process of differentiation entirely distinct from that discussed in the case of the gabbro.

EXPLANATION OF THE PLATES.

Plate XVI.

Sketch-map of part of the Carrock Fell district, showing variation of gabbro. (Scale: 6 inches = 1 mile).

An attempt is made here to show the distribution of the several varieties of gabbro and diabase. The criterion used is the specific gravity of the rocks, and the data are shown by figures on the map. These are chiefly in the eastern part of the gabbro area, and the dividing lines farther west are drawn with reference to the general characters of the rocks judged by eye and checked by a certain number of specific-gravity determinations, as shown. The specific gravity of the gabbro is seen to increase rapidly from the central zone to either margin. The rock here termed diabase shows much less variation.

The remarkable relations between the gabbro and the granophyre are not shown in detail, and the numerous dykes and veins are not marked.

The general distribution of the enclosed masses of Eycott lavas is roughly indicated. It would be impossible to represent accurately the intricate relation between these volcanic rocks and the enveloping gabbro.

Plate XVII.

Note.—The figures are magnified 20 diameters, and, except no. 2, are drawn in natural light. The numbers in brackets refer to the slides, which are in the Woodwardian Museum, Cambridge.

Fig. 1. [79]. Gabbro, White Crags (from Mr. Ward's collection). This shows the dominant pyroxene, an augite with fine lamellation parallel to the basal plane. This is combined with simple twinning parallel to the orthopinacoid, giving the 'herring-bone' structure. The augite is seen to mould the felspar-crystals. See p. 317.

[1] No chemical analysis of this rock has yet been made. The specific gravity of one specimen was as high as 3·122.

Fig. 2. [1867]. Gabbro, Iron Crags, about 200 yards W.N.W. of the sheep-fold. This is drawn with polarized light (crossed nicols) to show what seems to be secondary twin-lamellation on both the albite- and the pericline-law in the plagioclase. In one part of the crystal the pericline-twinning affects only alternate albite-lamellæ. Other crystals in this slide show albite-lamellation in evident relation to the strain attending flexure. The dark line is a crack in the slice. See p. 316.

Fig. 3. [1874]. Gabbro, top of White Crags. The figure shows idiomorphic crystals of plagioclase moulded by a shapeless plate of more uniformly turbid, untwinned orthoclase, well seen in the upper part of the drawing. Lower, and to the left, is an interstitial patch of micro-pegmatite, in which the felspathic constituent is probably also orthoclase. Pyroxenes and iron ores do not appear in the portion of the slice figured. See p. 318.

Fig. 4. [2046]. Metamorphosed gabbro, Brandy Gill, 50 yards north of the upper 'Bield.' This is a very basic marginal variety of the rock, unusually rich in prisms of apatite, which are seen in abundance. The rock is profoundly modified by thermal metamorphism, the pyroxene being wholly transformed, partly into green actinolitic hornblende, partly into matted patches of brown mica-scales. The latter mineral occurs characteristically in the neighbourhood of the grains of iron ore, from which it has probably taken up some ferrous oxide and titanic acid. The clear grains in the lower right-hand part of the figure are portions of one crystal of felspar, divided by narrow veins now consisting of brown mica. The clearness of the felspar seems to be a characteristic of the metamorphosed gabbros. See p. 334.

Fig. 5. [1526 and 1866]. Grains of iron ores in the gabbro. The example on the right, from the upper part of Furthergill Sike, shows irregular patches of magnetite (black) and ilmenite (grey). That on the left, from near the top of the same sike, shows the two minerals forming parts of one idiomorphic crystal, the dividing line being parallel to a crystal-boundary. See p. 318.

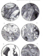
Fig. 6. [1622]. Modified Gabbro, crags in upper part of Furthergill Sike. This is from the actual margin of the gabbro, and is a highly basic variety, of specific gravity 3·122, rich in apatite (see upper part of figure). Nevertheless it contains quartz and micropegmatite (lower part of figure). This is probably due to an injection of the already consolidated gabbro by the later granophyre-magma, in the manner described by Prof. Sollas. At Carrock Fell this action seems to be exceptional, and is confined to the immediate contact of the two intrusions. Other parts of this slide and other specimens of the same rock show various phenomena of thermal metamorphism in the gabbro. See p. 335.

Discussion.

Mr. Marr believed that the age of the gabbro intrusion had yet to be determined. The Author's work had for ever set at rest the idea that the gabbro had been formed by alteration of the volcanic rocks of the Eycott group; for the proofs of intrusion of the gabbro into these were complete. The mode of occurrence of the gabbro and granophyre reminded him of the description of masses of these rocks in Scotland, about which the Society had recently heard much. These were points of local interest, but the main object of the paper was to describe the variation in the different parts of the gabbro mass, and from what he had seen of the district he believed that the Author had established his points.

Prof. Judd congratulated the Author of the paper on taking up this


CARROCK FELL DISTRICT.



highly interesting district of Carrock Fell as a subject of study. He bore testimony to the careful investigation of the area by the late Clifton Ward. The Author's observations seemed to show that concentration by crystallizing processes might go on in a mass of large dimensions, as well as in dykes like those described by Lawson and Vogt.

Prof. COLE expressed the regret which all must feel that Prof. Sollas could not be present to join in the discussion. The parallelism of the so-called granophyre and the several layers of the basic rocks seemed to suggest that the whole Carrock Fell mass might be a huge composite dyke, the acid rock having intruded into the gabbro distinctly on the north, and farther south as a plexus of minute interpenetrations along the central line of the gabbro, giving rise there to the gabbro with micropegmatitic groundmass. The microscopic sections seemed to him to support this view, by reason of the contrast between the basic areas and the patches of micropegmatite. The aggregation of iron ores on the margins of the gabbro must, however, be explained by some such theory as that which the Author had put forward.

Mr. RUTLEY considered that one of the most interesting points in this valuable paper was the occurrence of lavas of the Eycott series in the gabbro. How portions of lava-flows should become embedded in a plutonic rock was a problem which seemed to need further elucidation. The question whether the more acid character of the central portion of the gabbro was due to differentiation of the original magma, or to incorporation, by fusion, of apophyses from the adjacent granitic rock, was an open one; but it seemed probable that, if the latter hypothesis were the true one, the alteration, where the gabbro was seen to come into contact with the granitic rock, should extend over a wider area than that represented in the section.

The AUTHOR thanked those who had spoken for their remarks. In reply to Prof. Cole, he said that, while believing in a probable genetic relationship between the granophyre and the gabbro, he did not think that the injection-theory of Prof. Sollas afforded any explanation of the regular distribution of the more or less acid varieties of the gabbro.

Replying to Mr. Rutley, he described the occurrence of the masses of Eycott lavas enclosed in and intricately veined by the gabbro, but always with a sharply defined junction. All the phenomena negatived the hypothesis of a metamorphic origin for the latter rock.

22. Notes *on some* Trachytes, Metamorphosed Tuffs, *and other* Rocks *of* Igneous Origin *on the* Western Flank *of* Dartmoor. By Lieutenant-General C. A. McMahon, F.G.S. (Read April 11th, 1894.)

During the last two seasons I have spent some time in the examination of the rocks of igneous origin which occur between Lydford and Okehampton, and which are beyond the area dealt with by Mr. Frank Rutley, F.G.S., in his memoir on the 'Eruptive Rocks of Brent Tor and its Neighbourhood.' As these rocks do not appear to have been described, some details regarding them may be of interest.

On the Geological Survey map a long outcrop of 'greenstone' is depicted running from Great Cranaford, to the east of Sourton, almost as far as the West Okement River. The present paper is principally concerned with the outcrops of this 'greenstone' on Sourton Tors, South Down, and Meldon, and it will be found that they embrace a considerable variety of rocks.

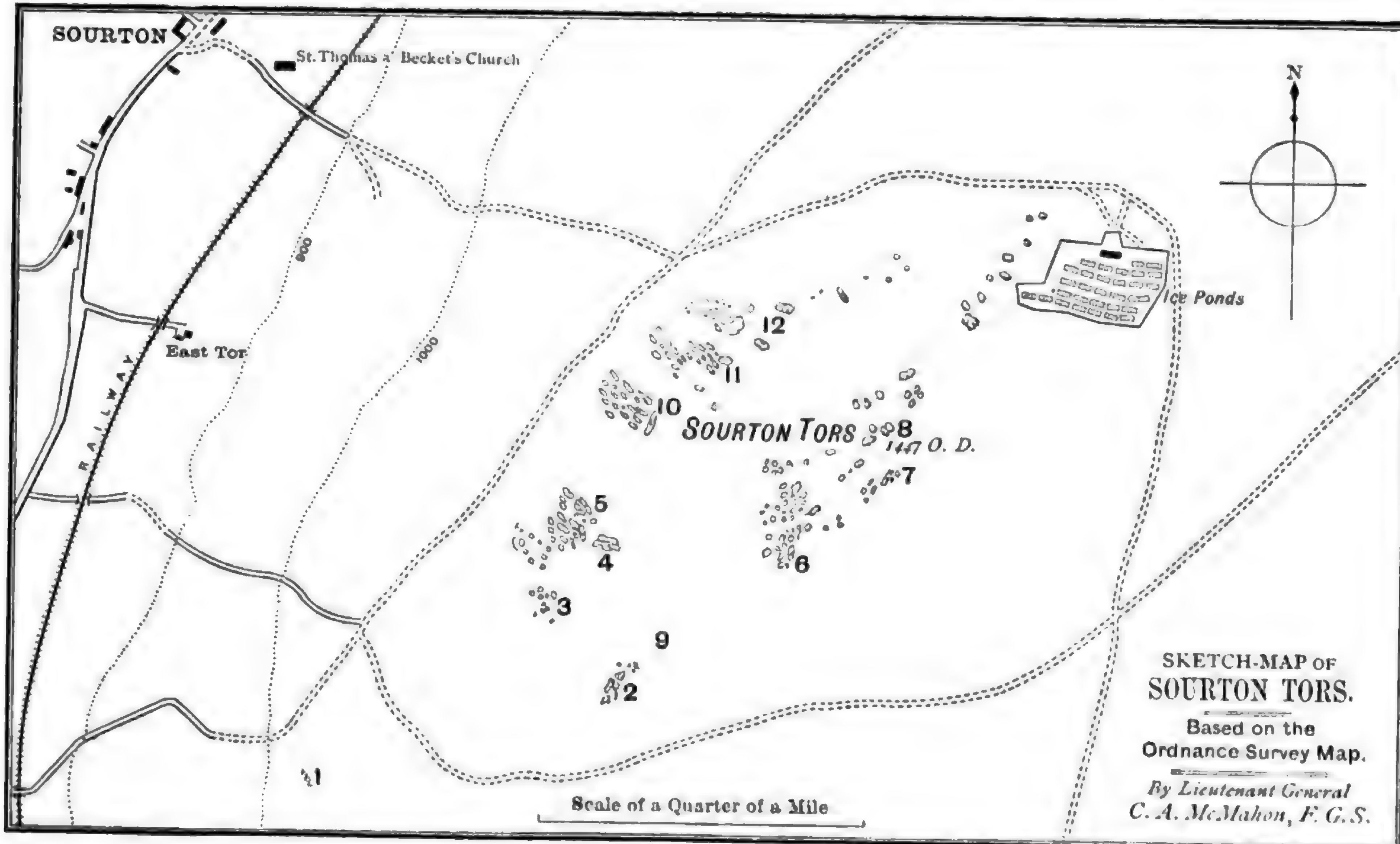
I. Sourton Tors.[1]

Sourton Tors form a ridge to the south-east of the village of Sourton (see the accompanying sketch-map). It rises to the height of 1447 feet above the sea, and 650 feet above the village. The rocks along this ridge crop out in two distinct lines; one of these—that on the western side of the ridge—forming a series of disconnected outcrops which I have numbered 3, 4, 5, 10, 11, and 12; and a second or eastern line, which I have marked 2, 6, 7, and 8 on the accompanying map. The space between these two lines is covered with grass, and the rocks between them consist, it is to be presumed, of sedimentary rocks of the Carboniferous (Culm) series, similar to those seen along the line of strike in the railway-cutting to the S.W. of the Tors. No. 1 (of map) is on lower ground, about 447 feet below the highest point of the Tors, and is lithologically connected with the second outcrop. No. 9 (of map) is described in detail farther on.

The sedimentary rocks along the road between the villages of Lake and Sourton—namely, on the western side of the Tors—dip N.N.W. In the railway at the Lake end of Sourton Tors, the strata dip about 60° to the W.N.W. 10° N. On the eastern crest of the Tors there is a small projection of a calcareous sedimentary rock dipping N.N.W. 10° N. I am not certain, however, that it is in place. But on the north-eastern flank of the Tors the sedimentary carbonaceous rocks crop out *in situ*, near the boundary of the Dartmoor granite, on the left bank of a stream running down from Sourton Tors to the West Okement River. The dip is here N.W. 10° W.

The general dip of the rocks which form Sourton Tors may, I think, be taken to be about N.W., and if so, the outcrop of the rocks of igneous origin, about to be described, conforms to the dip of the sedimentary beds.

[1] This is written Sourton Tor (in the singular) on the one-inch Ordnance map.



SKETCH-MAP OF
SOURTON TORS.
Based on the
Ordnance Survey Map.
By Lieutenant General
C. A. McMahon, F. G. S.

The rocks of the eastern line of outcrop, 2, 6, 7, and 8, exhibit two sets of joints at right angles to each other, the principal one dipping about N. 10° W., the dip being steeper than the sides of the hill. Both these sets of joints simulate bedding-planes, and the apparent dip depends upon which of the two series of joints is locally dominant.

The western line of outcrop (3, 4, 5, 10, 11, and 12 of the map) consists of porphyritic epidiorite, to be next described.

I have examined under the microscope thin slices of specimens from these outcrops as follows:—

No. 1[1]	1137.	Sp. Gr.	2·97.
„ 2	1126.	„	2·92.
„ 3	1213.	„	2·91.
„ 4	1214.	„	2·86.
„ 5	1133.	„	2·84.

These are dark-grey rocks, with an almost compact matrix in which numerous porphyritic, somewhat rounded crystals of white felspar are embedded. They are all altered dolerites, and were originally composed of augite and felspar. The remains of unaltered augite may be still seen in four out of the five specimens, being especially prominent in Nos. 2, 3, and 4.

The augite has been altered into a light-green hornblende. Sometimes the unaltered core of augite, colourless and non-pleochroic, with an extinction-angle of from 35° to 38°, remains in the centre of a crystal, while the pale-green pleochroic hornblende, which surrounds it, extinguishes at an angle of 5°. The original augite played the part of groundmass, the felspar appearing as large porphyritic crystals, and also in lath-shaped prisms penetrating into, and embedded in, the pyroxene. The felspar is intensely altered, having been converted either into a pale-green chloritic substance or into a serpentinous-looking isotropic mineral. Ilmenite is very abundant in all the slices; two of them contain a little mica; two possess apatite; and one of them a little granular calcite.

There is nothing to show that these rocks contained olivine.

Volcanic Tuffs.

The following rocks, from the places marked 1, 2, 6, and 9 on the accompanying map, have now to be described:—

No. 6	1127.	Sp. Gr.	2·80.
„ 7	1134.	„	2·79.
„ 8	1217.	„	2·77.
„ 9	1140.	„	2·75.
„ 10	1227.	„	2·74.
„ 11	1128.	„	2·74.
„ 12	1210.	„	2·73.
„ 13	1212.	„	2·73.

[1] Nos. 1 to 57 are the serial numbers of the specimens described in the paper, and are given for the convenience of the reader. The higher numbers are those marked on the band-specimens, and refer to the author's English collection.

The above specimens have a dark-grey matrix with blebby-looking crystals of felspar embedded in it. Several specimens also show rounded grains of quartz on their surface; and all exhibit, here and there, well-formed but rectangular crystals of felspar which give these rocks the appearance of lavas. On the other hand, many of these rocks when examined in the field contain numerous undoubted fragments of slaty, and of volcanic rocks; and the observer is puzzled to know whether he has before him highly metamorphosed tuffs, or lavas crowded with included fragments.

The difficulty here presented is not at once removed by an appeal to the microscope, and I have never examined any rocks regarding which I felt so much difficulty in finally making up my mind. That these beds contain a vast number of fragments of various kinds of lavas, and of slaty rocks, cannot be questioned. But the cementing matrix, which encloses these undoubted fragments, has so completely lost all trace of its original fragmentary origin; it so closely resembles the base of some quartz-porphyries and some rhyolites, and has so entirely lost all trace of the agencies by which the change was effected, that I was for long in doubt as to whether I was dealing with a metamorphosed tuff, or whether some, if not all, of the beds, were lavas that had caught up the contents of an ash-bed in the course of their flow, or had been profusely peppered with fine ash on their road from the crater to their final resting-place. The conclusion at which I have finally arrived is that the majority of the beds are metamorphosed tuffs, but that in two or three cases the rocks are really igneous flows that have in their passage through, or over, ash-beds caught up numerous fragments of ejected volcanic and sedimentary material. I propose to postpone further remarks on the subject until I have described these, and some other specimens, from another locality. I shall make my description as brief as possible and limit myself to salient points.

No. 6. This contains fragments of several kinds of lavas. The rock has been considerably altered and contains much secondary micaceous matter.

No. 7. This contains numerous fragments of lavas and of altered sedimentary rocks. One of the former class is a very dark glassy lava, full of the dust of magnetite, and contains numerous small oval vesicles and some microlites of felspar. Fragments of this rock are very commonly met with in these tuffs.

The interstitial matter in which the fragments are embedded is like the micro-granular base of some rhyolites and porphyries; and it eats into, corrodes, and invades some of the fragments, some portions of which appear to have floated off into the matrix and to have become more or less completely detached from their parent fragments. It is difficult to say offhand whether this corroding base represents an intrusion into a tuff, or whether the tuff was partially remelted after it was laid down.

No. 8. This rock is composed of numerous fragments of the dark, vesicular lava above described. The vesicles are stopped with a

pale yellowish-brown mica and in some cases with opalescent quartz. The fragments are pierced and invaded by a cryptocrystalline magma, which contains a great quantity of anthophyllite. reddish to yellowish-brown mica, and some quartz.

The anthophyllite is in bundles and sheaves of fine, needle-like, radiating prisms without crystallographic terminations. It is colourless in thin sections and consequently not dichroic. It polarizes in the yellow of the first order; it has straight extinction; the major axis is at right angles to the length of the prism; and it is not decomposed by prolonged heating in hydrochloric or in sulphuric acids. Its refraction is considerable, as it exhibits sharp and dark outlines. In a cross section I obtained two cleavages meeting at 127°. All the facts above stated seem to indicate that the mineral is anthophyllite: it is evidently a secondary product, and occurs principally in the base, or matrix, but it is also to be found sparsely in the included fragments, more particularly along their margins.

The magma, or base, has frequently eaten its way into the included fragments, these tongues sometimes terminating in a *cul-de-sac*; at other times pieces of the included fragments have been detached, drawn out into strings, and included in the fluxion of the magma.

No. 9. The hand-specimen does not, on its fractured surface, give any indication of being a clastic rock, but under the microscope fragments of three distinct rocks can be made out; one a highly crystalline lava; another a compact, buff-coloured felsite; and a third, which may be an altered sedimentary rock or the micro-granular base of a rhyolitic lava. A line of shear comes between fragments of the 2nd and 3rd class, and eye-shaped patches of both rocks are entangled with each other.

No. 10 was from a loose block not *in situ*, as will be explained farther on. Macroscopically considered, the hand-specimen is seen to contain numerous, small, slaty-looking fragments. The microscope reveals the presence of pieces of six or seven different lavas, all extremely fine-grained, but differing from each other in colour and structure. The interstitial cement (metamorphosed fine volcanic dust that originally filled up the interstices between the fragments) can be made out in parts of the slide; but in other parts, its place is taken by a rhyolite composed of two differently-coloured glasses, and containing porphyritic crystals of quartz and felspar. This rhyolite corrodes and invades the included fragments, and carries off small pieces detached from them in its course. It indicates the intrusion of a rhyolitic felsite into an ash.

No. 11. This is very much the same kind of rock as the last. The fragments are of the same varieties of lava, and the intruding rock is evidently the same as that seen in No. 10, only it has lost its rhyolitic character somewhat and has passed into an ordinary felsite. The rock has ceased to be an ash, and has become an igneous rock full of included fragments. The fragments are not so numerous or so closely packed as in No. 10, and probably indicate that the rhyolitic felsite was beginning to get clear of the ash.

No. 12. That part of the hand-specimen which is mounted on the slide appears to be one of the slaty inclusions in one of these ash-beds. It is of micro-granular but homogeneous structure, shows no distinctive marks of igneous origin, and much resembles a slice I had made from a slaty inclusion in a lava from this part of Sourton Tors.

No. 13. This is a rock of similar character to Nos. 10 and 11, but the included fragments have become sparser and smaller, and seem to have been, in most cases, nearly melted down and assimilated by the igneous rock. Its rhyolitic character has disappeared. The groundmass is finely crystalline-granular, with microlites of felspar dotted about in it here and there. Sometimes these microlites are sharply defined, and have forked ends; at other times they are somewhat ragged and irregular at their side edges: all of them have straight extinction. In this groundmass are embedded numerous porphyritic quartzes and felspars, some of which are idiomorphic. The felspars have straight extinction, and are orthoclase; some show a somewhat irregular polysynthetic twinning. One large felspar of this character, the irregular twins of which extinguish symmetrically at 18° to 19°, contains endo-idiomorphic crystals of felspar with binary twins, one of which is certainly orthoclase.

This slice contains a mineral of exactly the same habit and general character as the anthophyllite of No. 8. Some of it has a pale-yellow tint, and some of the prisms are slightly dichroic. The extinction varies from 0° to 15°. The mineral in this case must be actinolite: a slight rise in the percentage of iron has probably determined the change in the optical character and species of the mineral. The slice moreover contains magnetite, ferrite, and a mica, which varies from buff to red in colour. The last-named mineral also fills the vesicles in one of the included fragments of lava, as it often does vesicles in other specimens: it dissolves readily in hot dilute hydrochloric acid, and the solution yields a little lime and alumina, much iron, and magnesia in perceptible amount. It also reacts for potash. This mica must be lepidomelane or an allied species.

Felsites.

It will be seen from the above account of the volcanic tuffs of Sourton Tors that the pyroclastic rocks are intercalated with felsites containing numerous fragments of ejected material. It is not therefore a matter for surprise to find the pure felsites (described below) occurring among these beds.

No. 14	1136.	Sp. Gr.	2·76.	From place marked	6 on Map.
„ 15	1223.	„	2·74.	„	8 „
„ 16	1211.	„	2·72.	„	1 „
„ 17	1216.	„	2·72.	„	6 „

Nos. 14 and 17 are from the same locality, and are identically the same rocks. Macroscopically considered, they are perfectly compact in texture, with blebs of quartz and very minute grains of felspar visible here and there. They are also traversed by fine

quartz-veins. They have somewhat the appearance of a metamorphic sedimentary rock.

Under the microscope this rock, at first sight, has very much the character of a metamorphosed sedimentary rock, and seems to consist of a granular mixture of quartz and flaky greenish-brown mica. On closer examination, however, particularly with somewhat high powers, it is seen that the matrix is by no means all composed of quartz and mica, and that cryptocrystalline felsitic matter predominates over the clear grains. All the water-clear grains, moreover, are not quartz, for in some I obtained in converging polarized light traces of biaxial interference-figures. In this granular groundmass are scattered crystals of quartz and felspar, some of which are idiomorphic and yield sharp crystallographic outlines. These idiomorphic crystals afford, I think, decisive evidence of the character of the rock. I have seen a groundmass of identically the same structure in some undoubtedly igneous rocks, as, for instance, in some of the laccolites of the Henry Mountains, U.S.A.

Slice No. 14 contains much, and No. 17 a little, blue schorl in ophitic aggregations, its crystalline form being interrupted by the granules of the groundmass. Some of the large quartzes contain numerous liquid cavities with bubbles.

No. 15. The main constituent of this rock is a purple-brown glass, containing countless grains of magnetite arranged in fluxion-lines, microlites, and small prisms of felspar. The microlites have straight extinction, but the small prisms are in part plagioclase and in part orthoclase with binary twins. The glassy groundmass is vesicular, the oval vesicles being now stopped with red iron oxide, magnetite, and a colourless isotropic substance. The slice contains a portion of an included fragment of a fine-grained sedimentary rock.

There are numerous lacunæ in the brown glass, and they contain water-clear felspar, a network of green hornblende-prisms, and some massive hornblende without crystallographic shape. Congeries of green hornblende-prisms are also scattered through the glass.

No. 16. The groundmass of this specimen is substantially the same as that in Nos. 14 and 17, but it contains a much larger amount of pale-greenish mica, in scales and fibres.

The porphyritic crystals of quartz and felspar are extremely abundant in this specimen. They all show very distinct remains of crystallographic outlines; but they are, especially the quartzes, deeply corroded by the groundmass. The large felspars, on the other hand, have suffered very much from the formation of quartz and water-clear felspar (in some cases it is certainly quartz) in their interior. Very often this alteration has gone so far that the crystals have acquired a very decided granophyric structure. That this is, in these rocks, the result of secondary alteration I have no doubt. In the felspars that exhibit this structure small circular rings of quartz, or water-clear felspar, marking the passage of liquids, or gases, through the rock, have been left as evidence of their former presence. The centres of these annular bodies are filled with secondary mica, and they are sometimes fringed with the same mineral.

The record left by this rock is interesting, inasmuch as it shows that granophyric structure may in some cases, at all events, result from secondary alteration, and does not in these cases proceed from hurried crystallization, and from the imperfect separation of the quartz from the felspar at the time of consolidation.

All the felspars appear to be orthoclase, and exhibit a single twinning combined with simultaneous extinction. In many of the orthoclases of these rocks, however, there appear to be intergrowths sometimes of microcline and sometimes of plagioclase. The extinctions sometimes point to the former, and sometimes to the latter mineral.

Trachytes.

No. 18	.... 1220.	Sp. Gr. 2·75.	From place marked 7	on Map
„ 19	.... 1221.	„ 2·67.	„ „ 8	„
„ 20	.... 1222.	„ 2·67.	„ „ 8	„
„ 21	.... 1218.	„ 2·66.	„ „ 7	„
„ 22	.... 1219.	„ 2·65.	„ „ 7	„
„ 23	.... 1215.	„ 2·63.	„ „ 6	„
„ 24	.... 1226.	„ 2·62.	„ „ 9	„

The trachytes at 6, 7, and 8 are all exposures of lava-beds *in situ*; they occur on the eastern edge of the eastern line of outcrop, and therefore come in below the ash-beds. The spot marked 9 is situated about 50 yards on the north side of the crest of the ridge, and there is a bare patch here with no turf on it, the turf having apparently been removed by the hand of man. On this bare space there are loose blocks of trachyte (No. 24 is a specimen taken from one of them), of ash (No. 10, described on p. 342, is one of these), and of black, carbonaceous, sedimentary rocks. Whether these loose detached blocks represent a bed of coarse agglomerate cropping up in place, or whether they are surface-detritus that accumulated here at some remote period, I cannot say.

All the above specimens (18–24), with the exception of No. 23, are light-coloured rocks—whitish to whitish-grey on their newly-fractured surface—and have the rough vesicular appearance of trachytes.

The microscopical examination of thin slices yielded the following results:—in all except Nos. 19 and 23 the groundmass is composed of a felted mass of microlites of felspar, with some micro-prisms of the same mineral, of somewhat larger size. In No. 19 the groundmass is cryptocrystalline to micro-granular, and more resembles the groundmass of the felsite previously described. In the great majority of cases, and probably in all, the porphyritic felspars are orthoclases, and exhibit binary twinning and straight extinction. Many of them also show a very irregular striping, which sometimes is at right angles to the direction of elongation or to the plane of binary twinning, but generally is parallel to those directions, and indicates an intergrowth of microcline or of some other species of triclinic felspar. The striping has not the regularity, nor does it exhibit the straight planes, of plagioclase; and in many cases

the extinction is 15° from the plane of twinning in both sets of polysynthetic twins, or straight in one set and approximately 15° in the other set of twins. This is very characteristic of all the orthoclases in the lavas in this vicinity, and shows that intergrowths of microcline with orthoclase are not uncommon. The cross hatching, so commonly seen in the microcline of granites, has not been observed in these rocks. In many cases the felspars are idiomorphic.

Nos. 19 and 20 contain grains of free quartz in the groundmass, and these possess liquid inclusions with bubbles.

All the slices contain matted fibrous masses, and more or less radiating tufts, of fine needle-like prisms of actinolite. In habit it is like the anthophyllite of No. 8; in these slices it varies in colour from a pale-greenish to a brownish-yellow. Here and there it is slightly dichroic. The angle of extinction varies from 0° to 16°; the major axis of elasticity is at a high angle to the length of the prisms; and the mineral is not acted on by prolonged heating in concentrated hydrochloric acid.

The secondary origin of the actinolite is evident from the fact that it extends, in some cases, from the body of the rock into the quartz-veins that traverse some of the slices. This is an interesting fact, as it shows that the genesis of the actinolite was contemporaneous with the formation of the quartz-veins. As the quartz in these veins contains liquid cavities and bubbles, I think it probable that the actinolite and the quartz are both due to the contact-action of the neighbouring Dartmoor granite. In No. 20 the actinolite is of distinctly yellow tint and seems to be on the road to conversion into epidote. In double refraction, however, it is far from this mineral.

All the slices contain more or less magnetite, ilmenite, or ferrite.

No. 21 contains some lacunæ stopped with a chloritic-serpentinous mineral associated with quartz. No. 22 contains apatite, No. 19 a little hæmatite, and a red to green mica in leaves and radiating fibres. Digestion in hot concentrated hydrochloric acid removes much of the colouring matter, but does not dissolve the mica.

No. 23 is darker in colour than the specimens described under the head of 'trachytes,' being a light greenish-grey on the freshly-fractured surface, and rusty-looking on its weathered face. Decomposition has advanced so far in this specimen that I find it impossible to state definitely what its original structure was. It seems to have been a lava, and that is all I can say.

Remains of what appear to have been felspar-microlites and fine lath-shaped prisms of that mineral can be made out, but they are highly altered; they have straight extinction. The slice is profusely dappled with leucoxene after ilmenite, the inclusions in the original ilmenite remaining. There are also a few specks of magnetite or ilmenite.

The slice contains an abundance of calcite, in tabular twinned crystals and dotted all over the field in minute granules. A pale yellowish-green to almost colourless, serpentinous-looking, isotropic, and structureless substance occurs in patches and in lacunæ.

No. 23 also contains sphene and apatite. The former is rather abundant in small granules and crystals: it is a secondary product, sometimes embedded in the serpentinous substance, and at other times associated with the leucoxene.

II. Meldon.—West Okement River.

At Meldon, under and near the railway viaduct, there are some interesting rocks, the outcrop of which is entered in De la Beche's geological map as 'greenstone.' Owing to vegetation and talus, no actual exposure of these rocks can be seen on the banks of the river below the viaduct, and their relationship to the sedimentary series cannot be made out from an examination of the bed of the stream; but, judging from the manner in which they crop out higher up, and on the downs above, the 'greenstones' appear to run with the bedding of the Carboniferous strata, and to dip at the same angle and in the same direction as these.

The following specimens from the outcrop adjoining the viaduct have been sliced and examined:—

Volcanic Tuffs.

No. 25	1196.	Sp. Gr. 2·71.
„ 26	1197.	„ 2·72.
„ 27	1198.	„ 2·70.

Viewed macroscopically No. 25 would, I think, be taken for a lava; for, besides blebby crystals of felspar in a compact base, there are many small, lath-shaped, idiomorphic crystals of the same mineral orientated in various directions. A prolonged study of this specimen under the microscope has, however, satisfied me that we have here only an ash which has suffered from contact-metamorphism. The rock is really compounded of fragments of trachytic, felsitic, and other lavas of somewhat more basic character, cemented together in what now looks like the base of a felsite. This cement, or base, contains great quantities of the anthophyllite described under No. 8 (p. 342).

The slice also contains a reddish-brown mica, a little quartz, and dots of magnetite or ilmenite, leucoxene, and ferrite.

Owing to the fragments of which the rock is composed being of much the same colour as the matrix, it is only here and there that the unaided eye is able to distinguish between them. Many of the lath-shaped prisms may therefore belong to included fragments, and not to the matrix, but I am prepared to admit the possibility that they may be the products of metamorphism.

Nos. 26 and 27 are rocks of a similar character. The melting-down process has gone so far in these specimens that they simulate very closely the appearance of igneous rocks, and they might easily be taken for rhyolites. They betray their origin, however, by the numerous fragments of different kinds of lavas which they contain. Alteration has proceeded very far in both specimens. Mica in

scales has been profusely formed in the matrix, and also in the felspars, producing, in some cases, the appearance of their having been corroded by the groundmass. Dots of magnetite are arranged in flowing lines, and there is a general appearance of fluxion-structure, especially in No. 26. It does not seem necessary, however, to assume that any extensive movement of the ash actually took place. These fluxion-lines may only indicate that the fine volcanic dust was arranged in flowing lines of lamination round the larger fragments, and gave a direction to the heated aqueous agencies that subsequently acted on the rock. On the other hand, the very fine dust that must have formed the original interstitial portion of these ashes, when subjected to the aquose heat radiating from the great masses of Dartmoor granite may have become sufficiently plastic to assume a fluxion-structure under the stress of some of those minor earth-movements, or tremors, that were doubtless abundant in this region during the time when the granite was cooling down.

No. 26 must have been at one time in a plastic condition and must have been subjected to some pressure, because in one place an elongated felspar is bent round an included fragment, and cracked transversely in several places. But the amount of movement and shearing must have been slight, because several sharp angular fragments and felspars stand up boldly at right angles to the lines of apparent fluxion, and the felspars have not become eye-shaped, but, on the contrary, retain the sharp-broken, fragmentary outlines which they received when blown out of the mouth of the crater. Most of the cracks in these felspar-fragments are probably due to the explosion which ejected them from the crater; but the rock was, I conceive, subsequently subjected to *partial* aqueous-fusion and compression. I regard this specimen as a very beautiful example of the way in which a pyroclastic rock may, under the influence of powerful contact-metamorphism, be made to assume the appearance of a lava.

Near the railway viaduct some of the agglomeratic beds contain quite large blocks of slaty and felspathic rocks, of all sizes and shapes. I have examined a fragment from one of these blocks:—

No. 28, 1160. This is a fragment of a felsite. The matrix is microcrystalline-granular and contains porphyritic crystals of felspar and quartz, with dots of magnetite, ferrite, and leucoxene. These crystals have suffered corrosion from the base.

This slice is chiefly interesting, because the production of granophyric structure in one of the felspars appears to be directly connected with a quartz-vein that runs up to it. This vein is not an aqueous infiltration along a crack: the margins are not straight, well-defined lines; and the quartz appears to have eaten into the matrix on either side of the vein. This case supports the opinion expressed in describing No. 16 (p. 345), that granophyric structure in some cases, at all events, is due to secondary alteration.

In this connexion it may be desirable to allude to a vein that, at

the time of my visit, was to be seen cutting across these altered ash-beds, at right angles to their strike. I sliced and examined a specimen of it, No. 29, 1161. The slice is composed entirely of quartz and a pale yellowish-red mica. Some of the mica is in radiating groups: it has little dichroism and feeble double refraction. There are also colonies of colourless belonites. The quartz is like the quartz of the neighbouring granite: it contains a profusion of gas and liquid cavities, some separate, some combined. Some of the liquid cavities contain three or four rectangular crystals, as well as a bubble.

It is not improbable that this quartz-vein emanated from the white granite of Meldon, which is at no great distance. I mention the occurrence of this vein for what it is worth, as other better examples may hereafter be found; and such veins, if they can be associated with the granite, will elucidate the question of the relative ages of the granite and the rocks of volcanic origin in this locality.

On the Geological Survey map, another outcrop of 'greenstone' is marked to the S.E. of the white granite between Black Down and Longstone Hill. On going up from a tributary of the West Okement River and mounting the flank of the Black Down, blocks of this outcrop are seen which weather like a coarse-grained agglomerate. The dip of the rocks here is N. 20° W.

Volcanic Tuffs.

No. 30	1200.	Sp. Gr. 2·70.	Specimens of these rocks.
" 31	1201.	" 2·69.	
" 32	1202.	" 2·69.	Matrix of this agglomerate.
" 33	1203.	" 2·65.	One of the included blocks.

No. 30 is made up of fragments of trachyte, and of altered sedimentary rocks embedded in a very fine-grained microcrystalline-granular matrix, which equals in amount, if it does not predominate over the fragments. The matrix must originally have been a very fine dust. No. 31 is so completely composed of trachyte that its clastic structure is not at first apparent. This, however, came out more clearly in a second and thicker slice, which I had prepared for chemical purposes, particularly before it was subjected to the action of hot acid.

No. 32 is the matrix of a coarse-grained agglomerate, and 33 is a portion of a large included fragment. Under the microscope No. 32 is seen to be made up of fragments of trachytic and altered sedimentary rocks, embedded in a microcrystalline-granular ground-mass. No. 33 is a piece of trachyte traversed by several quartz-veins, which, as is commonly the case in these rocks, exhibits a micro-tessellar structure.

All the slices contain a profusion of mica varying in colour in transmitted light, from orange to greenish-brown; the mineral is completely soluble in hot, dilute hydrochloric acid. The solution contains iron, alumina, magnesia, lime, and potash, and the mica therefore appears to be some species allied to lepidomelane.

All the slices contain magnetite. Nos. 30 and 32 contain much, and 33 a little anthophyllite with the habit already described.

III. South Down.

On the left bank of the West Okement River, opposite Meldon, a ridge rises abruptly from the river, and stretches away until it widens out into South Down and ultimately merges into Sourton Tors.

I may note in passing that I discovered, last year, a second outcrop of the Meldon white granite on the eastern flank of South Down. It is not on the spot where a second outcrop is marked on the Survey map, which I stated in my last paper that I was unable to find. That is placed on the right bank of the river, extending in a northerly direction across to the left bank. The outcrop which I found is away from the river altogether, on the eastern side of South Down, some 300 feet above the West Okement River. A small quarry has been opened here, and the rock has exactly the same appearance as that of Meldon. The latter is, as the crow flies, about $\frac{7}{8}$ mile distant in a north-easterly direction.

In the Carboniferous slaty rocks that compose the ridge running up from the West Okement River to South Down, and at a lower horizon than the Meldon limestone, a plagioclase-mica-hornblende rock occurs which merits notice. It is a compact igneous rock of purple-grey colour which has the appearance, in the field, of being a contemporaneous lava. It runs with the sedimentary rocks; and although, owing to vegetation, its outcrop is not continuous, it is always found under a dark-blue slaty Carboniferous rock, that, in the field, is somewhat suggestive of a limestone. Though the mica-diorite disappears from view occasionally, it can always be found cropping up again farther along the line of strike.

The Carboniferous beds dip N.W. 15° N. at the foot of the ridge; higher up they dip N. 20° W. This dip continues until a wall is reached, which forms the boundary between the top of the ridge and the beginning of South Down: here the rocks make a sharp bend, the strike becoming N.E. 10° N. On the top of South Down the dip turns over to W.N.W.; that is to say, it reverts approximately to what it was in the bed of the West Okement River at the foot of the ridge.

The mica-diorite now described crops out first (specimen 35) on the flank of the spur, or ridge, just above the river. It rises to the crest of the ridge (specimens 34 and 36), and, owing to the sharp bend in the strike of the rocks above alluded to, it passes along the eastern side of South Down. I have not traced it beyond that point.

In my last paper I pointed out that De la Beche's geological map is not to be relied on too implicitly for the boundaries of the 'greenstone'-outcrops marked on it. The case in point is another instance of this; a continuous outcrop is indicated from the West Okement River over South Down to Great Cranaford. No such outcrop exists: the rocks of igneous origin visible along this line

are in discontinuous outcrops, and the rocks themselves, as has been shown above under the head of Sourton Tors, differ materially from each other.

The following specimens of the rock under description were examined:—

Mica-diorite.

No. 34	1144.	Sp. Gr.	2·81.
„ 35	1205.	„	2·79.
„ 36	1207.	„	2·79.

The microscopical examination of these specimens shows that the rock is a mica-diorite. The groundmass consists of a meshwork of small plagioclase-prisms, some of which are sufficiently large to show porphyritic crystals. The next most abundant mineral is a red mica; this is profusely scattered over the thin slices in all the specimens, and to its abundance the purple tone of the grey colour of the rock is due. It is, I think, a secondary contact-mineral.

Hornblende is not a prominent mineral, and it is altogether absent in No. 35. This mineral occurs in shapeless aggregates of grains, or in stumpy allotriomorphic prisms. In transmitted light it varies from a pale brownish-dun colour to a very pale undecided green. It is dichroic only here and there, and never strongly so. Only one cleavage is distinctly seen; and when a trace of a second cleavage is to be observed (which is rarely the case), it approximates in its angle of intersection more to hornblende than to augite. Extinction varies from 12° to 28½°, measured from the single cleavage, and averages 18°.

Sphene is abundant; so is apatite; and there is a fair amount of magnetite or ilmenite.

In the triclinic felspars extinction is often nearly simultaneous in both sets of twins, and is nearly straight. In others it varies from 6° to 14° from the plane of twinning on P, and averages 10½°.

IV. On the Flank of Cock's Tor.

High up on the southern flank of Cock's Tor, above the Tavistock and Moreton Hampstead road, there is an interesting outcrop of rocks, which have not, so far as I am aware, been described, or indeed noticed, by previous observers. These rocks stand out from the hillside in a low cliff about 12 feet high, and for a length of 40 or 50 feet. They weather out into lines suggestive of lamination, which impart a ribbed appearance, somewhat like that of corduroy cloth, to the beds. They have a low dip to the N.N.W. 10° W.

The ribbed appearance above alluded to is well seen on the weathered surface of one of my hand-specimens (38), and it is represented in the illustration (fig. 1, p. 352).

On the occasion of my first visit to this locality, in 1892, I collected the specimens numbered 45 to 47; but at my last visit in 1893 I made a more complete collection, in ascending order, which I enumerate on the following page:—

No. 37, the bottom bed, appears to be a true sedimentary rock. The fractured surface, examined macroscopically, resembles a slate, and it has two parallel white streaks running across it. This impression is confirmed by an appeal to the microscope. A fine-grained parallelism of structure pervades the whole slice: the micro-grains are arranged in parallel lines; and there are streaks of lighter colour running parallel to each other and to the alignment of the grains. The slice contains no porphyritic crystals; it is made up of minute colourless granules, crowded with microscopic fibres and leaves of mica. It contains strings of ferrite, and a fine-grained white substance, opaque in transmitted light, that may be kaolin. This rock is evidently a variety of slate.

Nos. 38, 40, 43, and 46, the specific gravity of which varies from 3·15 to 3·27, are shown by their microscopical characters to be identically the same rock. They are all composed alike of masses of augite-crystals set in a felsitic base. Sphene is plentiful in No. 40 and is present in No. 46. Apatite is abundant in No. 46.

The base is quite subordinate to the augite. In ordinary transmitted light it is of a reddish-buff colour, and, with the exception of No. 40, it is without any structure; it looks like, and plays the part of a glassy base. Between crossed nicols it breaks up into allotriomorphic masses of dimly-polarizing felspar. In No. 43 this base, or groundmass, is paler in colour; and though it is allotriomorphic as regards the augite, and shows no internal crystalline shape, it exhibits a single cleavage and straight extinction.

The augite is of a very pale greenish or bluish-green tint, but is nearly colourless. It is massed together in stumpy prisms, which rarely show its crystalline form perfectly. Sometimes, however, the cross-cleavage and the shape are typically developed. The extinction measured from a well-marked single cleavage usually varies from 35° to 45°. When cross-cleavages are visible the biaxial interference-figure, as in typical augite, can be seen.

Here and there, this nearly colourless augite has occasionally been converted *in situ* into a strongly pleochroic, greenish-blue hornblende; but the augite is, on the whole, extremely fresh, and the proportion of the paramorphic hornblende to the unaltered augite is very small.

In Nos. 39 and 47 the augite is in microscopic grains, and the base,[1] when examined between crossed nicols, differs from the base of the specimens previously described, inasmuch as it exhibits a micro-crystalline-granular structure—like the base of some rhyolitic rocks and the matrix of the tuffs at Sourton Tors and Meldon. Both specimens contain sphene, and No. 39 contains apatite and a little secondary hornblende. The comparative lowness of the specific gravity of No. 39, namely 2·85, is apparently due to the increase in the proportion of the acid base to the basic augite

[1] I prefer this term, in the case of these rocks, to 'groundmass,' because in ordinary transmitted light it is without structure, looking like and playing the part of a glassy base.

No. 41, both macro- and microscopically considered, is seen to be made up of two distinct layers. Under the microscope the purplish layer is seen to be almost wholly composed of fine granular augite, with a small proportion of the reddish buff-coloured felspathic base. The second, and greenish-coloured layer is made up of minute, slightly-elongated and irregularly-shaped grains of felspathic material that has a distinctly lamellar structure. This is dappled over with a granular, translucent to opaque substance, for which I have no name. Between these two layers the augite has passed into dichroic, finely granular hornblende.

No. 42 is essentially the same rock as the green portion of No. 41. The felspathic base is predominant and the pyroxene subordinate; hence the comparatively low specific gravity (2·65) of this specimen. The rock is composed of the felspathic base (in which a lamellar arrangement of the materials is apparent), with greenish hornblende, a little augite, some ferrite and opacite, a little sphene, and a little secondary quartz associated with the hornblende. The hornblende exhibits a linear arrangement of its crystals and granules parallel to the lamellar structure of the base, and is apparently due to the action of heated water acting along these lines of lamination.

No. 45 is essentially the same rock as the last. The lamellar arrangement above alluded to is not apparent in the base, and consequently this structure is not seen in the hornblende; but the study of this specimen leaves no doubt of the fact that the formation of this secondary hornblende is connected with the action of heated aqueous agencies, for one side of the hand-specimen (originally, I presume, the wall of a crack) is covered with hornblende, and numerous microscopic cracks, lined with this mineral and leading up to and traversing hornblende-crystals, may be seen in the slice. These crystals are in the form of more or less regular rhombs (the prismatic angle of one of them is 126°); internally they are made up of minute granular patches of hornblende, which here and there coalesce to form homogeneous platy crystals, exhibiting a single cleavage from which the angle of extinction measures 0° to 12°, with an average of 8°. Dichroism is distinct, though somewhat feeble. Extinction in the small patches is not always uniform throughout the rhomb, but this may be due to imperfect twinning.

This slice affords a very instructive example of the mode in which much of the secondary hornblende in these rocks owes its birth to active aqueous agencies permeating the pores of the rock.

No. 44 is a highly altered rock. It is composed principally of what appears to have once been a felspathic base and actinolite. In some parts of the slice there is much of what is probably zoisite; it is colourless, and its double refraction is so low as to be practically *nil*. One of my slices of this rock contains an abundance of sphene in grains and some iron, probably ilmenite.

The actinolite is of a pale green colour and occurs generally in

radiating fibrous crystals. Prolonged heating in concentrated hydrochloric acid has no effect upon it. It polarizes well, and, when the slice is sufficiently thick, exhibits pleochroism.

The original base has been altered into a serpentinous product, which is probably related to pseudophite.

These interesting rocks of Cock's Tor remind me very forcibly of some of the hornblende-schists of the Lizard. I allude to that variety of the Lizard hornblende-schists which is supposed to have been originally a volcanic tuff. This origin was attributed to the Lizard schists by De la Beche long ago, and was adopted in my first paper on the Lizard rocks.[1] In the joint paper subsequently written by Prof. Bonney and myself,[2] we stated that the rocks of the Hornblendic Group "must originally have been of igneous origin; the more massive may represent altered basaltic lavas, the more banded altered tuffs of similar composition."[3] And whilst the fluxion hypothesis was invoked to explain the present foliated schistose character of former lava-flows, we were of opinion that "the possibility of some portions [of the Lizard hornblende-schists] having resulted from the alteration of a stratified basic ash must not be left out of sight."[4]

My first paper showed that the Lizard hornblende-schists contain a colourless augite, and I expressed the opinion that the hornblende which enters so largely into the composition of these schists was a secondary product after augite. In these Lizard rocks the derivation of the hornblende from the augite could be clearly demonstrated by microscopical evidence.

In the rocks on the flank of Cock's Tor described in these pages, we have, it seems to me, hornblende-schists, similar to those of the Lizard, in an early stage of their development. In both we find almost colourless augite set in a felspathic base, or in felspar that plays the part of a base.[5] In the Lizard rocks the augite has nearly all been converted into hornblende; in the rocks of Cock's Tor this process has only just commenced, and we can see it in its first stages.

The microscopical evidence demonstrated clearly that aqueous agencies were the cause of the change of the augite into hornblende in the Lizard schists. In the case of the rocks of Cock's Tor, I think the evidence points to the same conclusion.

An original fragmentary origin was predicated for the Lizard hornblende-schists on the grounds that they exhibited structures suggestive of stratification and even of 'false bedding,' and that their chemical analysis and mineralogical composition indicated an igneous origin.[6] In the case of the Cock's Tor rocks, similar and even stronger grounds exist for considering them to be highly altered ash-beds. Their mode of occurrence is not only suggestive of bedding, but they bear on their face evidence of original lamination.

[1] Quart. Journ. Geol. Soc. vol. xlv. (1889) p. 519.
[2] *Op. cit.* vol. xlvii. (1891) p. 464.
[3] *Ibid.* p. 478.
[4] *Ibid.* pp. 480, 497.
[5] *Op. cit.* vol. xlv. (1889) p. 521.
[6] *Op. cit.* vol. xlvii. (1891) p. 478.

Weathering often brings out the original structure of rocks when the clean-fractured surface does not betray it, and the Cock's Tor beds are a case in point. The lines of original lamination weather out in a way which imparts to the weathered surface a peculiar ribbed appearance like that of corduroy cloth; this indicates, in my opinion, that these beds were originally sedimentary rocks deposited in thin layers. This structure is not only apparent in the field, but it is well seen on the weathered surface of one of my hand-specimens, which was selected for microscopic examination and not for the purpose of showing the surface-ribbing. The illustration (fig. 1) on p. 352, reproduced from a photograph of specimen No. 38, illustrates this fairly well, but the original, when seen in a suitable light, shows the lamination even more strikingly, because the growth of lichen and the consequent variation in tint somewhat interfered with the success of the photograph.

Evidence of this lamination is not altogether confined to the weathered surface of the rocks; it can be seen in some of the thin slices under the microscope, as for instance in Nos. 41 and 42. The linear arrangement of the felspathic portions of these slices, when seen between crossed nicols, is precisely that of a fine-grained aqueous sediment, and could be perfectly matched in numerous examples which I possess of the indurated slaty rocks of the Culm series bordering the Dartmoor granite.

The rocks (38–47) above described are mainly composed of pyroxene and felspar; they do not contain any water-worn grains of quartz, and their specific gravity averages as high as 3·00.

The above facts, taken together, seem to leave little, if any, reasonable doubt as to the origin of the rocks, and to show that they were once fine-grained beds of volcanic ash. Their high specific gravity, their mineral contents, and the absence of water-worn grains of quartz put the supposition of their being ordinary sedimentary rocks wholly out of the question; and the laminated structure, apparent on their weathered surface, is against the notion of their being igneous crystalline rocks. Moreover, their internal structure under the microscope is unlike that of any eruptive rock I have ever seen.

In order to compare these rocks with some of the Lizard schists, I selected for examination specimens taken from a quarry between Landewednack Church and Cove (Lizard). These are typical schists: they still contain some unaltered augite, and are without any free quartz. The specific gravity of the three samples examined was as follows:—(1) 3·00, (2) 3·05, (3) 3·17 (average 3·07). Their specific gravity, therefore, corresponds very closely with that of the ten Cock's Tor specimens.

I reproduce on the opposite page a sketch of a portion of No. 38 from Cock's Tor, as seen under the microscope, and a sketch of one of the Landewednack specimens, above alluded to, for comparison. The structureless portion in fig. 3 represents the felspathic base: the light-shaded part is the augite, and the dark-shaded part the secondary hornblende. I selected that portion of the Lizard slice in which the

augite was most abundant. The slice depicted in fig. 2 consists of felspathic base and augite; it contains very little hornblende, and the shading given by the artist is somewhat misleading in this respect.

Assuming that these rocks were originally ashes, it is evident that they must have suffered considerable metamorphism since they were laid down. There is no difficulty in accounting for this: the rocks under description occur within a few yards of the Cock's Tor epidiorite, and the epidiorites of this area are believed by previous writers to have exercised a metamorphic influence on the strata adjoining them.[1] Then the altered ash-beds here described are less than ½ mile from the main mass of the Dartmoor granite, and in its underground extension the granite may be even nearer than this. A subterranean connexion between the granite of Dartmoor and Brown Willy has been considered probable by those who have already written on the subject, from De la Beche to Ussher.[2] The rocks under consideration lie near the axis of this supposed underground extension of the granite, and the potency of the contact-metamorphism exercised by the Dartmoor granite has been admitted by numerous observers.[3]

As the massive dolerites, now epidiorites, have suffered so many mineral changes from the presence of the granite, it does not make a severe demand on our faith to believe that beds of finely triturated volcanic dust also felt the effects of the contact-action of the great mass of the Dartmoor granite, and of its underground extension between Dartmoor and Brown Willy.

These Cock's Tor beds appear to have been sufficiently distant from the nearest crater to have escaped the shower of coarse materials, and to have received only the fine dust borne upon the wind. No one who is acquainted with the history of Pompeii and Herculaneum, and has seen the deep and fine-grained deposits under which those cities are buried, need hesitate in believing that beds of equally fine-grained volcanic material, devoid of large fragments, may have been deposited at Cock's Tor. If so, I see no difficulty in going a step farther, and supposing that when the finely triturated particles of highly basic lava, charged with water, were subjected to the long-sustained heat and pressure which must have resulted from the intrusion of the great mass of Dartmoor granite, a reconstruction of the materials took place, and pyroxene and felspar were formed.

[1] I express no opinion on this point myself. The subsequent metamorphism by the granite renders the testing of this conclusion very difficult.

[2] W. A. E. Ussher, 'British Culm Measures,' Proc. Somerset Archæol. & Nat. Hist. Soc. vol. xxxviii. (1892) p. 193, where De la Beche is quoted.

[3] *Ibid.* p. 200; see also Teall, 'Brit. Petrography,' p. 234; Worth, 'Rocks of Plymouth,' Trans. Plym. Inst. vol. ix. (1886) pp. 242–246; De la Beche, 'Report on the Geology of Cornwall, Devon, and West Somerset,' 1839, p. 267; Allport, Quart. Journ. Geol. Soc. vol. xxxii. (1876) p. 421; Rutley, Geol. Surv. Mem. 'Brent Tor,' p. 25; and the writer's previous paper, Quart. Journ. Geol. Soc. vol. xlix. (1893) p. 389.

That the results obtained at Cock's Tor differed from those which followed the metamorphism of the Sourton Tors-Meldon ash-beds was probably due to some slight difference in the chemical and mineralogical character of the lavas that supplied the fine-grained interstitial material at Sourton Tors and Meldon, and the volcanic dust of Cock's Tor. There may also have been some slight difference in the circumstances that governed the metamorphism in the two cases. There may have been more water, or the water may have been more highly charged with acid, in the one locality than in the other; or there may have been greater heat, or some other factor, present in the one case that was absent in the other.

However this may have been, there is no escape from the fact that the Cock's Tor rocks are now composed of augite and felspar, and that these beds on their weathered surface give evidence of having once been laminated deposits. As these beds occur in an area that abounds in volcanic ash, and as this portion of the area exhibits contact-metamorphism of a pronounced kind, I think the most reasonable and probable conclusion to form is that they are tuffs which have been altered by contact-metamorphism.

In my first paper on the Lizard rocks I showed[1] that the hornblende of the schists was a secondary product due to the alteration of augite by aqueous agencies, and that examples of this change in all its stages can be seen in thin slices of these rocks when examined under the microscope; also that the rocks give "abundant evidence of the presence and action of water." "The competence," I added, "of this agent, aided by heat and pressure, to bring about great mineralogical and structural changes, can hardly be doubted. Indeed, the Lizard rocks have been penetrated by and have yielded to the action of aqueous influences so completely that they may almost be said to have been stewed in water."

The Cock's Tor rocks exhibit the same changes and the same agencies, only in a lesser degree. Here and there small portions of almost colourless augite-crystals (I speak of their appearance in transmitted light under the microscope) have been converted into a strongly pleochroic bluish-green hornblende—the beginning of those changes that would in time, and under favourable circumstances, have converted the metamorphosed ash-beds of Cock's Tor into hornblende-schists, indistinguishable from the Lizard hornblende-schists of tufaceous origin.

That the changes set up in the Lizard rocks have proceeded further than the changes begun in those of Cock's Tor may be owing to the circumstance that the rocks of the Lizard formed the roots of an ancient mountain-range, and were presumably more exposed than the Cock's Tor beds to the heat and pressure that gave greater potency to the aqueous agents at work: for the Cock's Tor beds, it is to be presumed, lay nearer the surface, and were consequently less involved in the pangs and throes of mountain-making.

[1] Quart. Journ. Geol. Soc. vol. xlv. (1889) pp. 522–527.

That hydrothermal agents played an important part in the formation of hornblende in the Cock's Tor beds is clear from the fact that some of my slices contain microscopic cracks stopped with this mineral, and a macroscopic crack on one of my hand-specimens was filled with the same material.

It may be convenient, before passing on to another locality, to compare the altered ash-beds (38–44), above described, with the nearest sedimentary beds.

No. 37, which conformably underlies these beds, would do well, so far as its lithological appearance is concerned, for one of the bottom Culm series. It looks like an indurated and altered Culm slate.

The next nearest bed that I was able to find cropped up on the side of the Tavistock and Moreton Hampstead road, under Cock's Tor, about ⅝ mile S.W. of the altered ash-beds above described. I have two specimens of this rock, but they are so exactly similar to each other that I need only describe one of them—viz., No. 48, 1116, specific gravity 2·74. Macro- and microscopically considered, this is much more highly metamorphosed than No. 37. Indeed, it is as much metamorphosed as the highly altered Devonian beds in the neighbourhood of Shaugh.

No. 48 is a fine-grained, spotted schist, with an unctuous feel. Under the microscope it is seen to be composed of plates and fibres of mica and fine-grained, irregularly-shaped granules of quartz. It is profusely dotted with countless grains of opaque to translucent ferrite, which imparts a redness to some of the mica, the colouring matter being diffused in streaks across the slice. The whole slice, under the microscope, has a streaky structure, and the spots are due to segregations of mica.

In Mr. Ussher's map, No. 1 ('The British Culm Measures'), the country east of Tavistock is marked as 'Culm *or* Devonian.' As regards the above-mentioned outcrops, I think No. 37 is probably Lower Culm; but I consider No. 48, on lithological and petrological grounds, as undoubtedly Devonian.

V. The Brent Tor Series.

It is not my intention to enter into any details regarding the Brent Tor volcanic rocks, so well described by Mr. Frank Rutley, F.G.S., in his work already referred to; but a few supplementary remarks, regarding rocks not noticed in his memoir, may not be out of place.

Due north of St. Michael's Church, which crowns the top of Brent Tor, on the side of the high road leading to the Tor, not far N.E. of the Stag's Head Inn, and S.E. of the old chimney of the abandoned mine at Monkstone, there is a pit from which the country rock is at present taken for road-material. This pit had not, I believe, been opened when Mr. Rutley visited the locality more than 17 years ago.

The rock exposed in this quarry is in some respects an interesting one. I collected three good specimens of it from different parts of

the pit, and have examined thin slices of them under the microscope.

No. 49	1101.	Sp. Gr.	2·92.
„ 50	1100.	„	2·98.
„ 51	1099.	„	3·00.

These are grey-coloured compact rocks, showing blebby-looking felspars sparsely scattered through them. Under the microscope the rock is seen to be composed of augite, pseudomorphs of serpentine, ilmenite, brown-red mica, sphene, apatite, a little secondary quartz, and the remains of large porphyritic felspars in what was probably a groundmass composed of felspathic material.

The augite, which is of a pale brown colour, is very fresh and, for the most part, in idiomorphic crystals, though some of these are to some extent corroded, internally and externally, by the base or groundmass. Apatite is abundant, and ilmenite is still more so. The latter has frequently been converted, in whole or in part, into leucoxene, or into sphene. The mica is of a rich brown-red colour, inclining to reddish yellow in thin leaves. The serpentine appears to be in part a pseudomorph after olivine and in part after augite. In some cases its derivation from the former mineral seems clear, for it is in rounded masses, or in six-sided and other forms characteristic of olivine. Sometimes the appearances under crossed nicols indicate decidedly the original structure of that mineral. The whole of the serpentine, however, cannot be referred to olivine. Some of it occurs in elongated or in large irregular shapes: this is more suggestive of augite, or some other variety of pyroxene; and it is material to note that some of the unaltered augite occurs in similar forms. Moreover, some of the serpentine exhibits a series of parallel cleavages which naturally suggest the pinacoidal cleavage of that mineral.

The large porphyritic crystals of felspar exhibit their original crystallographic outlines very well, but the felspar itself has quite disappeared, leaving behind opaque to translucent granular matter, with inclusions of steatite and talc, which probably represent what were originally endo-crystals of pyroxene enclosed in the felspar. Part of the original felspars have also been converted into an isotropic colourless substance.

The groundmass has been changed into opaque to translucent granular matter. I take it to have been originally a felspathic groundmass, because the secondary granular matter into which it has been changed seems to be the same as the granular matter in the porphyritic crystals, and because in some cases the augites are moulded upon what appear to have been lath-shaped prisms of felspar radiating from the groundmass into the pyroxene.

This rock was, in its unaltered condition, a dolerite.

Mr. Rutley has shown in his memoir that the present hill of Brent Tor is the ruin of an old volcano, and in figs. 7 and 8 of his paper in the Quarterly Journal (vol. xxxvi. 1880, p. 292) he places the cone in the immediate vicinity of the existing hill, and on its northern side. The position of the rock above described is

precisely that in which Mr. Rutley placed the throat of his volcano; and the rock itself would answer very well for a lava seething up in this neck from below.

VI. Was Tor.

Immediately north of the Lydford Junction railway-stations, and overhanging the G. W. Railway on its western side, is a little hill marked Was Tor on the Ordnance map. As the rocks exposed here have not been described in Part II. of Mr. Rutley's memoir, or alluded to in Part I. of that work, and as Mr. R. N. Worth in his 'Geological Notes on the South-Western line between Lydford and Devonport,' also passes them over without notice, a short description may be given here.

These rocks appear to be in the same line of outcrop as the Bowdon-Longstone 'greenstone' marked on the Geological Survey map; but the Bowdon 'greenstone' is represented as stopping more than ½ mile short of Was Tor.

I collected four specimens from the top of the Tor and two from an old quarry on its north-eastern flank. A short description of them is appended below:—

From the top of Was Tor.

No. 52	1108.	Sp. Gr. 2·68.
„ 53	1110.	„ 2·66.
„ 54	1109.	„ 2·94.
„ 55	1111.	„ 2·95.

From a quarry on the flank of Was Tor.

No. 56	1112.	Sp. Gr. 2·65.
„ 57	1113.	„ 2·68.

No. 52 is a highly carbonaceous shale, evidently one of the Culm series. This locality is coloured 'Lower Culm Basement Beds, Dolerites or Tuffs,' in Mr. Ussher's Map I. in his 'British Culm Measures.' Under the microscope the rock is seen to be made up of grains of sand, intermingled with carbonaceous material and minute flakes of mica. The carbon is arranged in wavy lines, and network of lines, and the whole structure is clearly due to deposition in water. The rock contains magnetite, but most of it has been dissolved out, leaving cube-shaped cavities. After the iron had been removed with hydrochloric acid the carbon was easily driven off by heat, the powdered rock becoming quite colourless.

No. 53 is a fine-grained sedimentary rock of somewhat slaty type.

No. 54 is of altogether different character. It is a compact rock, something between sage-green and grey in colour. It has not the smooth look or the unctuous feel of an ordinary serpentine, possessing a fine granular structure and an appearance of roughness on the fractured surface. In the field it would probably pass for an ordinary compact lava: its hardness is 3·5.

Examined chemically the rock was found to be a hydrated silicate of iron and magnesia. It also contained alumina, but this was quite

subordinate to the magnesia. There was only the faintest possible suspicion of lime. The acid solution reacted for titanic acid.

Under the microscope the base in transmitted light is of extremely pale tint, and seems to vary from a yellow-green to a green-yellow, and with high powers it is seen to be partly of obscurely fibrous structure, and in part amorphous: it is isotropic. In this base there are scattered patches and granules of doubly-refracting matter, which appears to be in part quartz, and in part felspar.

The slice is profusely dotted over with filamentous threads, fibres, and irregularly-shaped granules of leucoxene and magnetite or ilmenite. The high specific gravity seems due to the abundance of the iron and leucoxene.

In a second and thicker slice which I have had made of No. 54, and in No. 55 (a precisely similar rock), the original character of the rock is better shown. It would seem to have been composed of a network of small prisms (like the felspar-prisms in basalt), with larger prisms scattered about in the groundmass. There are also lacunæ which probably represent aggregations of pyroxene or olivine. Some of them would do very well for the latter mineral. In 55 the arrangement of the smaller dots of leucoxene suggests the former presence of a glassy base.

I think that Nos. 54 and 55 were originally basaltic lavas, and that they have been altered into a sort of serpentine. The shapes of the prisms remain, but the substance of the felspar and augite of which they were originally composed has disappeared. The resulting rock seems to be a variety of serpentine, which may be regarded as something between a normal serpentine and pseudophite. In other words, I take it to be a variety of aluminous serpentine.

There may be some finely granular or finely fibrous chlorite disseminated through Nos. 54 and 55, especially in the 'lacunæ,' but it cannot be identified as such, and, if present, its fibres must be so arranged as to produce compensation.

The beds on the top of the Tor, and those in the quarry below dip N.N.E.

No. 56, which occurs on the top of the quarry, is a dark bluish-black Carboniferous slate, weathering white, the surface of the weathered portion being tinted an ochreous yellow. The dark colour of the rock is due to the presence of carbon. Boiling in hydrochloric acid does not remove the colouring, but on the application of red heat the rock turns white. I have seen similar rocks in this area weather white on the surface, *and along cracks*, where no trap has been present, or, at any rate, where none has been visible.

No. 57, which crops out at the bottom of the quarry, under No. 56, is a rhyolite. The hand-specimen might be taken for a very fine-grained amygdaloid.

Under the microscope the groundmass is seen to be a glass showing fluxion-structure here and there, and sinuous streaking due to ferrite-staining. In this groundmass are numerous rounded and corroded crystals of quartz, and the remains of what were,

apparently, more or less rounded crystals of felspar. The felspars have been converted into a soft white substance (pale buff-coloured in transmitted light), which exhibits a feeble double refraction between crossed nicols: some of it has been partially replaced by quartz. Between crossed nicols the groundmass breaks up into an isotropic base; in this occur doubly-refracting fibres and irregular patchy aggregations of fibres, which are, I think, imperfectly developed mica. Here and there are undoubted leaves of mica. The slice also contains numerous granules of ferrite.

VII. Summary and Conclusion.

In the preceding pages I have noted the occurrence of felsite and trachyte at Sourton Tors; of rhyolite, and a variety of aluminous serpentine, believed to have been derived from a basaltic rock, at Was Tor; and of a dolerite in the exact situation indicated by Mr. Rutley as the probable position of the throat of the ancient Brent Tor crater.

At Sourton Tors, and at Meldon, on the West Okement River, I have recorded the occurrence of some interesting tuffs, the matrix of which has been converted by contact-metamorphism into what closely resembles the base of a rhyolite, and which, in extreme cases, exhibits fluxion-structure, or a structure indistinguishable from it. So complete is the resemblance which this matrix assumes to the base of an igneous rock that I was for long doubtful whether the rock was not a lava full of volcanic ejectamenta; but the extreme abundance of the fragments—pieces of six or seven different kinds of lava being sometimes visible in a single slice—taken into consideration with the extended area over which these deposits are to be found, convinced me that these beds are really metamorphosed tuffs.

The occurrence of other interesting beds on the flank of Cock's Tor, not noticed by previous observers, is also noted. These beds now consist of a mixture of nearly colourless augite set in a base which, in ordinary light, looks like a structureless glass, but which, between crossed nicols, is seen to be made up of obscurely crystalline felspar. Many rocks reveal on their weathered surfaces the secret of their primitive structure, and these beds do so in a striking manner; their weathered surface exhibiting a corded appearance, like corduroy cloth, that betrays, with a clearness that leaves little room for doubt, the existence of an original lamination. Certain appearances in some of the slides under the microscope confirm this supposition, and I consider that the Cock's Tor rocks were originally beds of fine-grained volcanic dust, which, in consequence of the intense contact-metamorphism engendered by the great mass of the Dartmoor granite, was converted into a mixture of augite and felspar.

In my first paper on the Lizard schists I showed that the latter contain numerous unaltered crystals of augite, and that the hornblende is a secondary mineral formed by aqueous agencies from the augite; in a joint paper written by Prof. Bonney and myself,

we adhered to the idea suggested by De la Beche, and stated that "the possibility of some portions of the Lizard schists having resulted from the alteration of a stratified basic rock must not be left out of sight." The evidence afforded by the Cock's Tor beds appears to establish the correctness of this hypothesis by revealing the first stage in the series of changes that converted a fine-grained ash into a hornblende-schist. The Cock's Tor and the Lizard rocks, studied together, also show that the main agents which effected the conversion of the augite into hornblende were aqueous, and that the lines of original lamination assisted the action of those agents; so that the alteration of the augite into hornblende went on hand in hand with the production of schistosity.

It only remains, in conclusion, to offer a few remarks on the relations of the epidiorite and the volcanic rocks. Some former writers have rather twitted De la Beche's Survey with having mapped such rocks as the epidiorite and rocks of volcanic origin (including ashes) under one wash of colour. But I am not sure that De la Beche was so entirely wrong as his critics supposed. Their criticisms were made under the impression that the rocks we now call epidiorites solidified under plutonic conditions, and several writers have called them gabbros. We know now that these rocks are only altered dolerites; and I do not think, from what I have seen of them, that we need regard them as of very deep-seated origin.

There is no actual evidence in the area embraced in this paper that the epidiorites are intrusive rocks. They certainly, in the Sourton Tors and Meldon area, appear to conform to the bedding of the ash- and lava-beds. I discovered no evidence of transgression in their relation to the sedimentary rocks, and I think that their intrusive habit may, in many cases, have been assumed from their supposed plutonic character. But even if they should ultimately turn out to be intrusive sheets, or sometimes sheets or dykes, and sometimes flows, I do not think this need necessarily divorce them from the volcanic eruptions of that period. Flows, sheets, and dykes are associated in almost every volcano; and in studying under the microscope samples of dykes and flows collected from the old crater-walls of Somma I could not discover any material difference in their structure. The epidiorites of the West of Dartmoor may have been comparatively deep-seated offshoots of the volcanic forces that seem to have opened up numerous volcanoes in this region during the Carboniferous age. I regard the numerous volcanic rocks in the Tavistock-Okehampton area as the outcome of several small volcanoes rather than of one large one.

Mr. J. G. Goodchild has shown in a recent paper[1] that a holocrystalline structure may possibly be set up by contact-action in the glassy magma of a lava, with the result that the rock assumes "a plutonic instead of a volcanic facies." That factor must be borne in mind in this region, where contact-metamorphism has been so active; but I do not think it necessary to fall back on that hypothesis

[1] Geol. Mag. 1894, p. 24.

in the present case. Prof. Judd has shown, in his well-known papers on the Western Isles of Scotland and on the ancient volcano of Schemnitz, that the igneous rock that was poured out at the surface as a lava when "undergoing consolidation at some depth from the surface assumed a most perfectly granitic character."[1] And he states in another paper that "the distinction between plutonic and volcanic rocks—however convenient and necessary it may be in practice—is a purely arbitrary one, some lavas being more highly crystalline than certain portions of intrusive masses."[2]

In the present case, to confine myself to the area embraced in this paper, I should say that the epidiorites are a long way short of being hypogene rocks (I have not found a particle of hypersthene or diallage in any of them), and that there is nothing in their microscopical *structure* to prevent them from being connected with the volcanic activity of the Carboniferous age.

Discussion.

Mr. Rutley considered that this paper would be of great value not only to those geologists who had already worked in the Brent Tor area, but also to those who might do so in the future. The augitic rocks described by the Author as occurring on the western side of Cock's Tor, rocks which had hitherto been completely overlooked, were of especial interest, and would have to be taken into consideration in the future mapping of the district. The discovery by General McMahon of a dolerite at the spot which had been indicated many years ago as the probable site of the original vent of the Brent Tor volcano was, he hardly needed to say, most gratifying to him. He briefly explained the old diagrams used in the illustration of his former paper, stating that one of the two faults, there indicated as bounding the downthrown portion of the cone, was first noted by the late Dr. Harvey B. Holl. A few remarks were also made upon the schistose lavas and tuffs of the neighbourhood, and on the great difficulty often experienced in assigning such rocks to their respective groups.

Prof. Bonney said that there were two points of great interest—(1) the alteration of the trachytic ashes, which seemed to be somewhat abnormal, and (2) the conversion of a basic ash into something like a hornblende-schist. The latter was a most important contribution to a very difficult subject. He was quite prepared to believe that hornblende-schist might have this origin, though his work in Sark had made him a little more doubtful than formerly about the origin of the hornblende-schists of the Lizard.

Mr. W. W. Watts also spoke.

The Author, in reply, indicated the exact position of the Cock's Tor beds, and thanked the Fellows present for the kind and sympathetic way in which they had received his paper.

[1] Quart. Journ. Geol. Soc. vol. xxxii. (1876) p. 323.
[2] *Op. cit.* vol. xlv. (1889) p. 191.

23. Note *on the* Occurrence *of* Perlitic Cracks *in* Quartz. By W. W. Watts, Esq., M.A., F.G.S. (Communicated by permission of the Director-General of the Geological Survey.—Read March 21st, 1894.)

[Plate XVIII.]

Contents.

I. Introduction.

Since the publication of Mr. Allport's classical paper[1] on the devitrified pitchstones of Shropshire, in which he drew some very cautious deductions from the presence of perlitic and other structures in rocks of felsitic character, it has been customary to regard perlitic cracks as an indication that the material in which they occur has once been in a glassy condition. In 1893 I came across a specimen (I 860), forming part of the old rock-collection of the Irish Geological Survey, which raised grave doubts as to the safety of this wide generalization. It was obtained from Sandy Braes, in Antrim, and was a specimen of the 'pearlstone' of Portlock.[2] When cut it exhibited admirable perlitic structure, not only in the glassy matrix of the rock, but also in the abundant porphyritic quartz-crystals which it contained.

Later on I found two specimens, collected by Mr. Rhodes, in the English Survey collection (I 926, 927), which exhibited the same characters, and one of them (I 927) was so well preserved as to allow a thin slide to be made from it. It is this slide from which the most satisfactory of the figures illustrating this paper have been taken.

The specimens were obtained from the quarries at Sandy Braes, 1½ mile N.E. of Tardree Mountain, in the northern part of the great rhyolite mass which is shown on Sheet 28 of the Geological Survey map of Ireland. I have reason to believe that the description of the petrological characters and field relations of these rhyolites is in very good hands, so that I do not propose to give an exhaustive description of the rocks; it is sufficient for my purpose to refer to the admirable descriptions of A. von Lasaulx.[3]

[1] Quart. Journ. Geol. Soc. vol. xxxiii. (1877) p. 449.

[2] 'Report on the Geology of Londonderry,' 1843, p. 212.

[3] Journ. Roy. Geol. Soc. Ireland, ser. ii. vol. iv. (1877) p. 227. and Tschermak's Min. u. Petrogr. Mittheil. vol. i. (1878) p. 410.

II. Macroscopical Characters.

The ordinary type of Tardree rhyolite is well known; it is a light grey, or pinkish-grey, trachytic rock showing fair-sized crystals of sanidine, smaller crystals of plagioclase, and some quartz, any ferro-magnesian mineral being decidedly rare.

The variety from Sandy Braes, which I have more particularly to describe, would be perhaps more appropriately termed a porphyritic pitchstone (or obsidian), composed of a pitch-black glass, with a lustre generally brightly vitreous, but occasionally more resinous. The perlitic structure is clearly seen with a lens, and as the rock fractures the projecting perlites stand out on its surface. Where the perlites are broken across the glass is seen to become much paler, and occasionally quite white towards their interior. Whilst the felspars break along cleavage-planes, it is seen that the quartz, instead of showing its customary conchoidal fracture, stands up in rounded grains, and is traversed by cracks roughly concentric with this outer surface. In some specimens there are a good many patches of a whitish substance, which may be devitrified glass. In specimen I 927 large irregular cracks with wavy surfaces are seen to enclose the perlites of the glass; these are frequently coated with a thin skin of hæmatite staining, and are the polygonal cracks to be afterwards described.

From Connor, Sandy Braes, have come several interesting varieties of the rhyolite, including the 'pitchstone-porphyry' of Portlock, and amongst them a greyish-green variety (I 861) with a horny-looking groundmass and small porphyritic crystals. In the cracks and cavities of this rock opal is not unfrequently deposited, as seen in the two specimens deposited in the Dublin Museum.

III. Microscopical Characters.

Von Lasaulx gives the following list of minerals as occurring in the Tardree rhyolites:—'Sanidine, clinoclase, tridymite, quartz, biotite, magnetite, epidote, apatite.' To this list I have only to add the following: very rare pseudomorphs after hornblende, and minute crystals of zircon and rutile.

These minerals are set in a brown translucent glass, sometimes perfectly pure, but generally containing abundance of minute trichites showing all the forms figured by Zirkel.[1] Grains of magnetite are also present, and minute microlites of felspar, which are generally forked and frequently are mere skeletons built in a negative crystal of glass. There is sometimes a very slight clearing of the matrix in the immediate neighbourhood of the magnetite. Occasional patches with trachytic structure are to be seen in the

[1] Zeitschr. Deutsch. geol. Gesellsch. vol. xix. (1867) pl. xiii. figs. 8 and 14, and pl. xiv. fig. 2.

glass, and sometimes these are surrounded by a few small felspar-crystals accompanied by magnetite.

There is nothing unusual in the development of the perlitic structure in the glass of these rocks. It is first traversed by two sets of polygonal cracks, running very rudely at right angles to one another, of which one set is generally much better developed than the other. The cracks cross where they meet, and usually one gives off a crack which curves round and joins the other tangentially (Pl. XVIII. fig. 2); inside the spaces thus formed come the perlites, which vary from ·05 in. to ·005 in. in diameter. Sometimes they are simple, with circumferential cracks passing down to a very small scale; but very frequently one perlite contains several others, like those figured by Allport[1] and the compound spheroids figured by Bonney.[2] Occasionally two perlites have one common flat side, and, in one case that I observed, two perlites have impressed a third which lies between them.

The cracks are usually filled up with a crystalline substance, which depolarizes under crossed nicols and gives a maximum extinction in that part of the crack to which the short axis of one of the nicols is tangential. This corresponds with several instances described by Rutley and with the infilling of perlitic cracks in the pitchstone ('felsit-pechstein') of Buschbad, near Meissen. In consequence of this infilling the cracks are always best, and often only, visible with crossed nicols; indeed, prolonged observation with high and low powers is necessary to appreciate the full perfection of the contraction-structures in the rock. Generally there is a dust of magnetite seen in those cracks which are oblique to the surface of the section, and this, in one section, increases in quantity to such an extent as to make the whole of the cracks black and opaque.

A very common feature is a close-set series of radial cracks which run at right angles to the concentric cracks. These are very well seen in Pl. XVIII. figs. 1, 2, and 6, and though they are more usual across the outer cracks of the perlite, they are by no means absent from the inner and innermost cracks. They are not usually continuous for any considerable distance, but are replaced by others on different lines; and this is especially the case in opposite sides of a perlitic crack. Similar fissures occur at right angles to the polygonal cracks, as shown in Pl. XVIII. figs. 2 and 3.

The contraction-cracks occasionally cause faulting in the flow-structure. This latter structure is marked in several ways:—(1) by light and dark glassy bands; (2) by darker glassy bands alternating with lighter bands, which have a larger number of felspar-microlites, or in which the groundmass is somewhat devitrified; (3) by dark, often twisted bands, in which there is an abundance of excessively minute magnetite-dust; (4) by stream-lines of dark trichites and the general arrangement of them; (5) by streams of felspar-

[1] Quart. Journ. Geol. Soc. vol. xxxiii. (1877) pl. xx. figs. 3 and 4.
[2] *Op. cit.* vol. xxxii. (1876) p. 151, fig. 13.

microlites. Faulting in flow-structure of the third type is seen in fig. 1, p. 371.

Occasionally perlitic cracks may be seen to traverse the trichites (as in the slide from which fig. 1 is taken), and at other times a similar fissure may be seen passing through a felspar-microlite. These phenomena are, however, difficult to observe, and are not likely to be common, because the perlitic cracks circle round the edge of the phenocrysts and the flow-structure determines the microlites to take a similar direction. It would be impossible to tell whether a crack, usually more or less oblique to the section, cut through the breadth of such minute microlites. The depolarizing granules are similarly seen to be cut through, without displacement, by the cracks.

A curious feature of the matrix-perlites is the frequent bleaching of their interior. The colourless centres are not as a rule devitrified, although this may sometimes occur; generally they are made up simply of a colourless glass, which passes gradually into the normal brown glass, and then, very occasionally, in the centre there is a group of fairly developed felspar-microlites. Inside a few of the colourless perlites the glass has been broken up by a number of irregular star-like fissures. In extremely few instances the very centre of the perlite is darker than the rest, and then there is a slight aggregation of trichites at that spot.

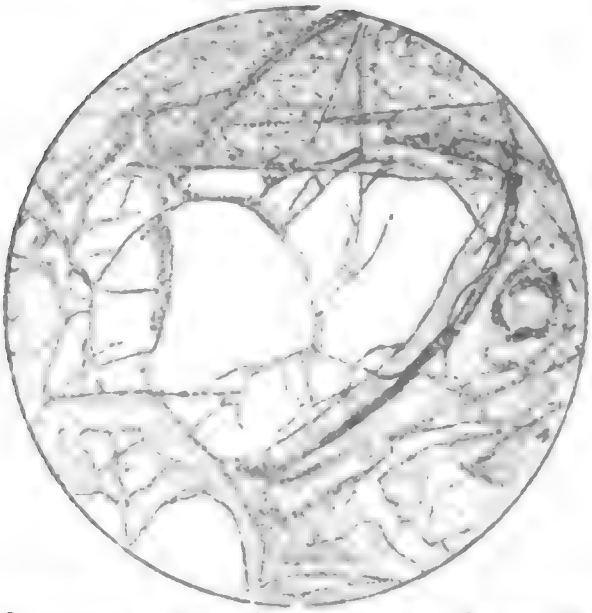
There is no optical evidence of strain in the perlites. Where the flow-structure is pronounced and of type 2 the perlites may occur only, or more frequently and with greater perfection, in the glass; or they may cut both the glass and the lithoidal portion; or, in still rarer cases, a single perlite will involve both structures, but its cracks will not be so clearly visible where they cross the lithoidal band.

IV. Perlitic Structure in Quartz.

In many of the rounded porphyritic crystals of quartz in this rock very fair examples of perlitic structure are to be seen, which are at least as perfect as those produced by the rapid cooling of Canada balsam. Indeed, I am able to show that not only are these cracks of a general perlitic nature, but that (1) the cracks pass outwards from crystals to matrix; (2) the matrix-perlites are sometimes completed in the quartz; (3) perlites are formed in quartz and completed in the matrix outside; (4) the polygonal cracks sometimes extend into the quartz and have the same characters as in the matrix; (5) the radial cracks are also to be found in the quartz, and even enter the quartz from the matrix.

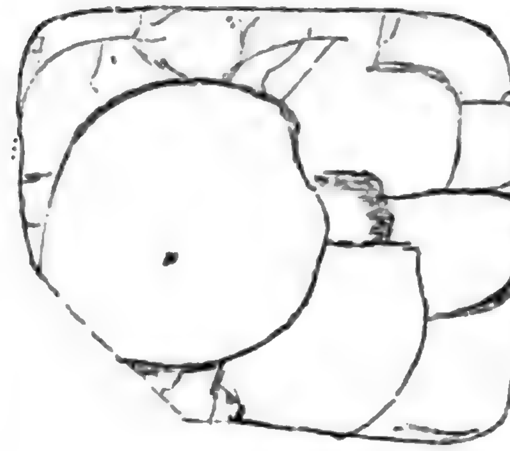
The general nature of the perlitic cracks in the quartz can be judged by reference to the figures. The most characteristic is, perhaps, that shown in fig. 2, where the inner crack is very perfect, and two outer cracks are connected with it by radial fissures. The same characters are seen in Pl. XVIII. fig. 4, in which the whole of the quartz is traversed by a series of curved cracks of a general

Fig. 1. × 25.



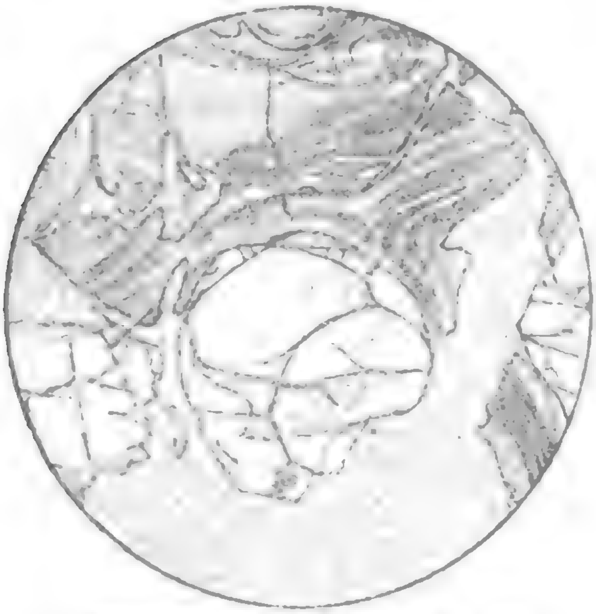
Continuity of cracks in quartz and matrix. Faulting of flow-structure by cracks; trichites in brown glass (I 927).

Fig. 2. × 25.



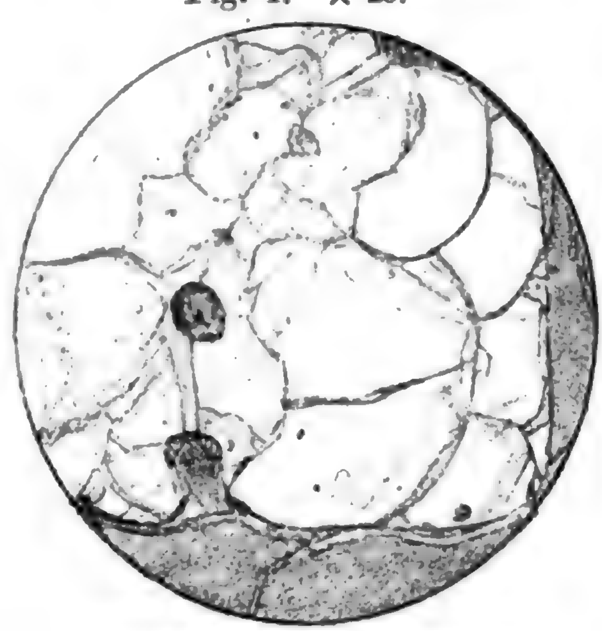
Concentric and radial cracks in quartz (I 926A).

Fig. 3. × 25.



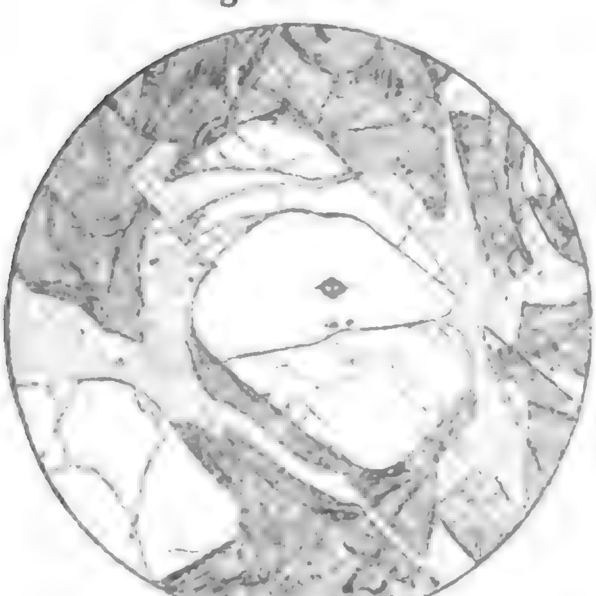
Concentric cracks in quartz; flow-structure in matrix (I 860).

Fig. 4. × 25.



Cracks of perlitic type in quartz; perlite in glass inclusion (I 860).

Fig. 5. × 25.



Quartz at centre of perlite, which is completed in matrix (I 927).

Fig. 6. × 25.

Quartz at centre of perlitic crack, which traverses matrix and neighbouring quartz (I 927).

perlitic aspect, which are clearly the result of contraction. Of these, one at the top passes from the quartz into the matrix, and then back again into the quartz.

Similar features, with some amount of variation, are visible in figs. 3 and 4 (p. 371), in both of which one or other of the cracks may be seen to traverse the matrix for part of its course. Inside a quartz-grain in fig. 4 there are perlitic cracks in a glass inclusion, while in another quartz from the same slide there is a tendency for the cracks to aggregate in the neighbourhood of a matrix inclusion.

Slide I 926 displays the difference in the behaviour of quartz and felspar under the cooling strain, the only cracks visible in the latter being those due to cleavage, while the practical absence of cleavage in quartz allows of the formation of spherical cracks. In Pl. XVIII. fig. 3 will be seen excellent polygonal cracks in quartz and matrix, with imperfect perlites in both substances.

It might have been supposed that the independent contraction of the quartz was responsible for the perlitic structure, and that it was quite apart from the generation of perlites in the matrix. A minute inspection of these figures will, however, show that occasionally some one crack or other penetrates from the quartz into the matrix, and may even return into the quartz; and an examination of the thinnest slice with very high powers shows many clear cases to prove that the glass and quartz must have shrunk and cracked together.

Fig. 1 represents a portion of the slide I 927 drawn with a 1-inch objective, but with the details put in from a $\frac{1}{5}$-inch. It is perfectly clear that the quartz is perlitic, and that there are at least four, and probably two more, cases of continuity of crack from quartz to matrix. There is generally a slight deviation in direction when a crack passes from one substance to the other; but this is very small, and the main trend of the crack is preserved. The drawing also represents diagrammatically the wisps and curls of the trichites and the deposit on the cracks, while it rouses a suspicion that the cracks have slightly faulted the edge of the quartz.

A more important case is presented in fig. 5 (p. 371), where the quartz is the focus of the perlite and is traversed by two of its cracks, at least one of which is continued for two thirds of the distance round the crystal in the matrix, although the actual continuity is obscured by a slipping of the section during grinding. Somewhat similar and perhaps clearer relations are displayed by fig. 6 (p. 371), in which the quartz is again at the centre of the glass-perlite and is surrounded by a crack which encroaches on the border of a neighbouring quartz-crystal; while in Pl. XVIII. fig. 2 a crystal of quartz is cut by two perlitic cracks, each of which traverses the matrix as well, both being included in a single circular crack, which does not touch the quartz. In Pl. XVIII. fig. 1, again, the quartz is the focus of a perlite which is completed in the matrix; fig. 1 *a* shows the outline of the quartz in this figure.

Two more important cases remain for description. In Pl. XVIII.

fig. 5 a large matrix-perlite is seen bordering a second, which has a perfect set of radial fissures. The outer crack of the first perlite, which goes off at a tangent, enters the quartz-crystal in the lower part of the figure, traverses it for a short distance, and then passes out into the matrix. The angle made by this crack with the average circumference of the perlite is not greater than that of its inner cracks where traversing the matrix only. A couple of radial fissures are given off by it, and, further, there is a set of polygonal cracks surrounding the principal perlite, with branch cracks surrounding subordinate ones; of these, two major cracks and one of a minor character occur and join up in the quartz. Pl. XVIII. fig. 6 gives an excellent example of a typical matrix-perlite contained in polygonal cracks, and giving off a great number of radial fissures. Some of the polygonal cracks are confined to the matrix, others just traverse the quartz, and radial cracks passing from the perlitic cracks of the matrix are seen to pass into the quartz and stop there at the junction with the polygonal crack (see Pl. XVIII. fig. 6 *a*).

When traversing quartz the cracks are generally filled with a deposit, sometimes of magnetite, generally associated with small granules or plates, probably of specular iron, and usually also with a deposit of a colourless mineral, which is likely to be quartz. A curious reticulated structure is seen in the latter, with which also a little chlorite occurs.

I have reserved till last the occurrence of the cracks in slide I 861, cut from the lithoidal variety referred to on p. 368. The matrix is traversed only by polygonal cracks, amongst which it is very rare to find anything approaching a perlite; indeed, I have only seen one in the slide. The matrix is not glassy, but consists of recognizable microlites of felspar (varying from ·001 to ·004 in. in length), often forked, and set in a cryptocrystalline granular substance. Immediately round the quartz, perlitic cracks are very frequent, but they very rarely avoid the quartz altogether; the large polygonal cracks of the matrix, however, in most cases avoid the quartz, passing round the crystals or being deflected very considerably before entering them. On reaching the felspars these polygonal cracks generally pass obliquely through them, stepping down along the cleavage planes. In the matrix cracks may sometimes be seen, though rarely for the reason given above, to cut and traverse felspar-microlites—making it quite certain that the lithoidal structure existed before the perlitic cracking, and that the matrix is in all probability original and not a devitrified glass.

V. Conclusions.

The facts recorded above allow us to draw the following deductions:—

1. That perlitic cracking is not inconsistent with crystalline structure, but is only likely to be developed where there is no good cleavage along which the strain would be more easily relieved.

2. That the cracking in the crystals has taken place after the rock became solid, as proved by the passage of cracks across the inlets of matrix occurring in the crystals, and, indeed, cutting across every constituent and structure of the rock, quartz, glass, felspar, microlites, trichites, and flow-structure.

3. That it is subsequent to the development of lithoidal structure.

4. That the occurrence of perlitic structure cannot be safely relied upon to prove that the rock has ever been in a glassy condition, but that the lithoidal matrix is in certain cases original.

5. That the glass of the rock has probably about the same coefficient of expansion and contraction as the quartz, but not quite, as there is always a little deflection in the cracks at the junction, and always a tendency for them to bifurcate at the edge of the quartz; but that in the case of lithoidal (trachytic) structure there is probably a considerable difference.

This is not the first time that the occurrence of perlitic cracks in crystals has been described, although the chief instances have not attracted much attention in England. MM. Fouqué and Lévy [1] in 1878 referred to two or three instances known to them:—"Dans le groupe des porphyres quartzifères nous trouvons la roche de Perseigne, près d'Alençon, qui présente des fissures sphériques développées autour et même au travers des grands cristaux;" and again, speaking of the hornblende-andesites of the region south of Santorin, "Les fentes de retrait traversent les grands cristaux."

Mr. Rutley, in his paper on the vitreous rocks of Montana,[2] says, "In the section to which our attention is now confined there are plentiful examples of doubly-refracting crystals which are immediately surrounded by perlitic cracks, but which do not, save very exceptionally, transgress those boundaries;" and again, "In those few instances in which a perlitic crack passes through a crystal, there is commonly another crystal developed by its side (p. 397)."

The circular cracks seen in olivine have often arrested the present writer's attention, and a description of them by Prof. J. P. Iddings, noting the likeness to perlitic structure, will be found in 'The Geology of the Eureka District, Nevada' (1892), Appendix B, pp. 387, 388, and pl. iii. fig. 11, Monographs of the U.S. Geol. Survey, vol. xx.

Slight traces of similar perlitic structures have been noticed in the pitchstones of Donegal and Newry, and also in the porphyritic crystals in some of the igneous rocks of Charnwood.

These instances would have rendered unnecessary any description of the specimen from Sandy Braes; but the chain of structures and evidence seemed so complete as to merit a detailed description.

[1] Comptes Rendus Acad. Sci. vol. lxxxvi. (1878) p. 771.
[2] Quart. Journ. Geol. Soc. vol. xxxvii. (1881) p. 391.

EXPLANATION OF PLATE XVIII.

All the specimens are from Sandy Braes, 1½ mile N.E. of Tardree Mountain, Antrim. The numbers refer to the series of sliced rocks in the collections of the Geological Survey of Ireland.

Fig. 1. I 927 A. Polygonal and radial cracks in matrix of pitchstone. Perlite centred in quartz and involving matrix. × 25.
Fig. 1 *a*. Outline of quartz in fig. 1.
Fig. 2. I 927 A. Radial cracks from polygonal and perlitic cracks. Matrix-perlite, enclosing two perlites which involve quartz and matrix. × 25.
Fig. 3. I 927 A. Polygonal and spherical cracks in quartz and matrix. $\times \frac{25}{2}$.
Fig. 4. I 927 A. Spherical cracks in quartz, some of which pass into the matrix. The cracks are filled with a brown deposit, showing reticulated texture. × 25.
Fig. 5. I 927. Matrix-perlite, with outer and polygonal cracks traversing quartz. × 25.
Fig. 6. I 927. Matrix-perlite, with radial cracks; polygonal and radial cracks traversing both quartz and matrix. × 25.
Fig. 6 *a*. Radial cracks at junction of quartz and matrix. × 125.

Note.—The drawing of each illustration in this paper has been carefully checked by photographs taken on the same or a larger scale.

Discussion.

Mr. Rutley remarked that the careful observations made by the Author appeared to be quite satisfactory up to a certain point, although he should hesitate to describe the cracks in the quartz and olivine-crystals as perlitic. That perlitic structure and the structures seen in these crystals were both due to shrinkage there was no question. Spheroidal structure in basalts and other crystalline rocks also resulted from the same cause, yet the spheroidal structure of a basalt and the perlitic structure of an obsidian were sufficiently different to deserve different names. He had occasionally met with cracks in olivine-crystals similar to those exhibited, but he had never regarded them as perlitic. On the whole, he considered that the Author had given the Society an extremely interesting and valuable paper, but he did not agree with him in thinking that the facts now brought forward were sufficient to invalidate conclusions hitherto formed with regard to the once vitreous character of rocks showing perlitic structure. In the absence of this structure it was not possible to say whether a felsite originally solidified as a lithoidal or as a vitreous rock, because, if originally vitreous, it might assume a lithoidal character through devitrification. Furthermore, if perlitic structure occurred in a lithoidal rhyolite, there was no means of proving that the rock was lithoidal when the perlitic structure was developed.

Mr. Harker thought the Author had proved that true perlitic cracks may be formed in a mineral like quartz, possessing no marked cleavage. He compared the phenomena with those recorded in the

Meissen pitchstone. There, according to Sauer, the generally peripheral arrangement of the cracks within the quartz-crystals indicated a greater contraction in the mineral than in the surrounding glass. In the rock now described, the frequent continuity of the cracks through glass and crystal alike pointed to a smaller difference between their respective coefficients of contraction.

Prof. J. F. Blake also spoke.

The Author, in reply to Mr. Rutley and Prof. Blake, pointed out that the perlites in quartz were of the same nature as those in the surrounding glass, that the two substances were often involved in the same perlite, but that the quartz cracks were often quite independent and frequently concentric. As the cracks traversed every structure in the rhyolites, including trichites and microlites, he felt no doubt that the felsitic structure was in this case original.

24. *On the* Origin *of certain* Novaculites *and* Quartzites.

By Frank Rutley, Esq., F.G.S., Lecturer on Mineralogy in the Royal College of Science, London. (Read March 21st, 1894.)

[Abridged.]

[Plate XIX.]

Although various explanations have been offered regarding the origin of certain novaculites it seems that more may yet be said upon this subject. A useful *résumé* of the opinions held by different authors is given in the 'Annual Report of the Geological Survey of Arkansas for 1890,'[1] by Mr. L. S. Griswold. Before attempting to explain my own views it seems desirable that I should allude briefly to the specimens upon which those views are based, and especially to the Arkansas novaculites, since Mr. Griswold's intimate acquaintance with these rocks, both in the field and in the laboratory, lends great weight to his opinions. Indeed, it may seem presumptuous on my part to question them, since I have no knowledge of the ground with which he is so familiar, and also because the material at my disposal consisted of two small specimens, while he has had mountain-ranges to work upon.

The specimen of Arkansas stone which I have examined is a bluish-white rock with a faint yellowish tinge, translucent in moderately thick splinters, breaking with a conchoidal to splintery fracture and bearing a general resemblance to chalcedony. The structure is cryptocrystalline, and it shows under the microscope the outlines of what were once cavities of rhombohedral form, now occupied by siliceous deposits of secondary origin.[2] The specimen of Ouachita[3] stone resembles a faintly yellowish-white or cream-coloured biscuit-porcelain, except that it exhibits barely a trace of translucency on thin edges.

Under the microscope this rock is also seen to possess a cryptocrystalline structure, but of somewhat coarser texture than that of the Arkansas stone. It likewise shows numerous little cavities, some of which have irregular boundaries, but a large proportion of them have the form of rhombs and represent cavities once occupied by crystals of a rhombohedral carbonate (Pl. XIX. fig. 3). The siliceous grains which form the walls of these cavities often show a regular arrangement, like a course of masonry (Pl. XIX. fig. 3); but beyond these borders the arrangement of the siliceous

[1] Vol. iii. 'Whetstones and the Novaculites of Arkansas.' I am greatly indebted to Mr. W. Topley, F.R.S., for calling my attention to this admirable work, and also for the loan of the book.

[2] This specimen appears to correspond with that described as 'Slide No. 31' of Mr. Griswold's series. *Op. cit.* p. 135.

[3] Usually spelt 'Washita' in this country. I adopt Mr. Griswold's spelling as doubtless the more correct.

grains is confused and quite irregular, just as one finds it in ordinary cases of cryptocrystalline structure.[1]

These general characters seem to agree perfectly well with the descriptions given by Mr. Griswold, who usually speaks of the rhombohedral cavities as having been occupied by calcite. On p. 188 of his work, however, he says that "the rhombohedral cavities undoubtedly contained crystals of calcite or dolomite."

Without entering at present upon the question whether the silica of the Arkansas and Ouachita stones is to be regarded as quartz or as chalcedony, but accepting for the moment Mr. Griswold's conclusion that it is the former, it will be best to quote some of the passages in his book which refer more especially to the origin of these rocks. Evidently he has felt it important to compare them with chert, and the following extract from his work,[2] headed 'Differences between Novaculite and Chert,' is therefore given in full:—

"Defining chert according to the weight of opinion as a cryptocrystalline siliceous rock formed by chemical action, and containing a large percentage of the silica in the chalcedonic form, it is now possible to state wherein the Arkansas novaculites differ from chert, and to present the theory of their origin. Chemical analyses tend to show that the novaculites of Arkansas have a purer siliceous composition than cherts, though if the calcite had not been dissolved from the Ouachita stone it could not have been distinguished from chert. The tests of solubility of the silica show a decided difference between novaculite and chert. Microscopic examination shows that the soluble silica of chert is in the form of chalcedony, while novaculite is entirely without silica in this form.

"As a result, apparently, of this difference in the form of silica, novaculite has a fine gritty feeling, while chert is more glassy. Owing also to the purer and more homogeneous composition of novaculite, this stone is more translucent than chert. Novaculite is not a tough rock like chert, and breaks more easily, though its conchoidal fracture is as perfect as that of any chert or flint."

With reference to Arkansas stone, there is one fact which seems to me to be of considerable importance, namely, that, under the microscope, the structure of Arkansas stone very closely resembles that of flint, in those portions of the latter which are free from organic remains (Pl. XIX. figs. 1 & 2). So close is this resemblance that when such a section of flint has been examined in polarized light, between crossed nicols, and a section of Arkansas stone is immediately substituted, no difference can be recognized between the two sections. One may, indeed, say that Arkansas stone and flint are practically identical in structure. The structure of Ouachita stone is similar, but somewhat coarser in texture.

[1] For these and for other specimens of hone-stones I am indebted to my friend Mr. Wm. Berrell, M.I.C.E., who procured them from Mr. T. Hazeon, of 10, Bishopsgate Avenue, E.C., the importer.

[2] *Op. cit.* p. 187.

The employment of a Klein's plate does not, in the case either of Arkansas or Ouachita stone, appear to indicate the presence of any appreciable amount of amorphous silica. Even in flint the close examination of single minute areas during a complete revolution discloses a change of tint in the Klein's plate, and it therefore appears that, at all events for the most part, the component particles of flint are doubly refracting.

So far as the presence of soluble silica in cherts is concerned, the researches of Prof. Renard[1] indicate that in those of the Carboniferous Limestone of Belgium the amount is extremely small. Moreover, the analysis, by Mr. E. T. Hardman, of one of the purest specimens of Irish chert examined by him gave 95·50 per cent. of insoluble silica, while only a trace of soluble silica was present.[2]

On treating a thin translucent splinter of Arkansas stone with fuchsine no appreciable staining was visible under the microscope. Without here questioning the opinions expressed by Mr. Griswold, which appear to be borne out by the analyses given by him, it appears to me strange that, although he notes the close resemblance of some of the Arkansas stone to chalcedony, he says nothing about the extremely close resemblance in microscopic structure between it and flint.

Prof. J. D. Dana defines flint as "somewhat allied to chalcedony, but more opaque," and with regard to the silica of which it is comcomposed, he adds that it, "according to Fuchs, is partly soluble silica."[3] Prof. Tschermak observes that it contains some opal substance, due to organisms.[4] Prof. A. de Lapparent, after alluding to the fibrous structure of chalcedony, as seen under the microscope, adds: "when chalcedony becomes very compact, with a more and more confused orientation, it passes into flint."[5] Finally, we have the researches of MM. Michel-Lévy and Munier Chalmas,[6] in which more exact methods of determining chalcedony and other forms of silica are employed, but in cases such as those which we are now considering no satisfactory results could be arrived at, so far as the determination of optical characters is concerned—one difficulty being that we are not dealing with fibres, but with granules of microscopic dimensions and of most irregular forms, so that there is no crystallographic direction of elongation upon which to base observations.

I have attempted to determine the optical sign in the *apparent* direction of elongation of some of the larger siliceous grains forming the border of a rhombohedral cavity in Ouachita stone, with the result that only alternate grains give a rise, while the intermediate produce a fall in the colour-scale when a quartz-wedge is employed.

[1] 'Recherches lithologiques sur les Phthanites du Calcaire Carbonifère de Belgique,' Bull. Acad. roy. Belgique, ser. 2, vol. xlvi. (1878) p. 494.

[2] 'The Chemical Composition of Chert, and the Chemistry of the Process by which it is Formed,' Sci. Trans. Roy. Dublin Soc. vol. i. (new series) p. 90.

[3] 'System of Mineralogy,' 6th ed. 1892, p. 189.

[4] 'Lehrbuch d. Mineralogie,' 3rd ed. 1888, p. 388.

[5] 'Cours de Minéralogie,' 1884, p. 340.

[6] 'Mémoire sur diverses Formes affectées par le Réseau Élémentaire du Quartz,' Bull. Soc. Min. France, vol. xv. (1892) p. 159.

In other cases in the same section I have obtained quite irregular results. Such differences are doubtless due to differences in the orientation of grains of the same character.

As already mentioned, little if any distinction can be made between the most chalcedony-like variety of Arkansas stone and those portions of a flint which exhibit no traces of fossil organisms. From this extreme it seems probable that gradations may be traced to coarser structural conditions, in which Ouachita stone represents an intermediate and quartzite an extreme phase of coarseness. This is partially shown on Pl. XIX. figs. 1, 7, & 8. Fig. 7 represents the thin edge of a section of a pebble from a conglomerate from Purtiall, in the Deccan. Except on the margin, this section exhibits what may be termed a cryptocrystalline structure on a large scale, while on the margin it shows a microcrystalline structure on a large scale, as in fig. 7. In this case the cryptocrystalline aspect is evidently due to the overlapping of crystals, while on the margin the section is only thick enough to include a film of juxtaposed, but not superposed, crystals. Fig. 8 is drawn from a section of a quartzite from Nondweni, Zululand, and represents what we may, for the time being, regard as the extreme phase of coarseness in this series.

I speak of these rocks as constituting a series, because I believe that they have all had a common origin, that they are all siliceous replacements of limestones. It is a generally recognized and, I think, an incontrovertible fact that a large proportion of quartzites are more or less altered sandstones, as clearly demonstrated by Irving and Van Hise.[1]

The former of these authors, when speaking of the genesis of the Huronian quartzites, stated that "all the true quartzites of the Huronian are merely sandstones which have received various degrees of induration by the interstitial deposition of a siliceous cement, which has generally taken the form of enlargements of the original quartz-particles, less commonly of minute independently oriented areas, and still less commonly of chalcedonic or amorphous silica: two, or even all, of the three forms occurring at times in the same rock."[2]

Fully admitting the truth of this statement, which deals only with 'true quartzites,' I am, nevertheless, inclined to think that it is needful, not on mineralogical, but on genetic grounds, to divide the rocks which might be generally termed 'quartzites' into two groups, including in the one group the indurated sandstones or true quartzites, which might, for the sake of distinction, be termed 'detrital quartzites'; in the other siliceous replacements of limestones which, at times, may simulate detrital quartzites both in mineralogical and structural characters. These might be termed 'infiltration or metasomatic quartzites.'

The necessity for such a classification I hope to render more apparent by dealing at some length with the rhombohedral cavities

[1] 'On Secondary Enlargements of Mineral Fragments in certain Rocks,' Bull. U.S. Geol. Surv. No. 8, vol. ii. (1884). [2] *Ibid.* p. 48.

and inclusions in certain siliceous rocks to which the name 'quartzite' is applied by some authors, and 'chert' by others.

Some of the cherts derived from the Carboniferous Limestone of Belgium, and described by Prof. Renard, contain rhombohedral crystals which, although very minute, give distinct reactions for magnesia, and these Prof. Renard regards, apparently with good reason, as crystals of dolomite.

In a section of a pebble from the conglomerate of Purtiall, in the Deccan, I have noticed the occurrence of similar rhombohedral crystals. Portion of a section of this pebble is represented in Pl. XIX. fig. 4, as seen between crossed nicols. The polarization-picture afforded by the quartz in this part of the section is suggestive, as I have already stated, of a cryptocrystalline structure, but the marginal portions of the section give distinct proof that the rock consists of small crystals of quartz and, could the preparation be rendered as thin in all parts as it is on the margin, it would doubtless appear, in polarized light, as a uniform mosaic of distinctly individualized quartz-crystals. One of those on the margin, represented in Pl. XIX. fig. 7, gave a positive uniaxial interference-figure.

The occurrence of small rhombohedral crystals of dolomite in "a flinty, grey or dark-grey jaspilyte from the shaft at the Breitung mine," Minnesota, has been pointed out and figured by Prof. N. H. Winchell.[1]

It has been considered doubtful whether the cavities in the Arkansas novaculites were originally occupied by calcite or dolomite. If these rocks represent the replacement of limestone by silica, it may, I think, be assumed with good reason that the limestone so replaced was either a dolomite or a dolomitic limestone.

There seems nothing unreasonable in such a supposition, since dolomites of Archæan age are known, and Huronian dolomites and dolomitic limestones occur in Michigan.[2]

Let us, in the first case, suppose the replaced rock to have been a dolomite. It is well known that dolomites consist, as a rule, of minute rhombohedra. A section cut from a specimen collected at Matlock, from one of the magnesian limestone-beds which there constitute part of the Carboniferous Limestone system, consists almost entirely of such small rhombohedra (Pl. XIX. fig. 5). An analysis which I made of this specimen showed it to be almost identical in composition with the typical dolomites of the Magnesian Limestone series, the calcium carbonate amounting to 51·25 and the magnesium carbonate to 42·18 per cent., the remainder consisting mainly of silica, with a little iron, alumina, and water. A small fragment of this specimen, when placed in dilute hydrochloric acid, let fall a fine granular deposit, the grains falling from the fragment

[1] 'The Iron Ores of Minnesota,' Geol. & Nat. Hist. Surv. Minn. Bulletin no. 6 (1891) p. 77, and pl. viii.

[2] Credner, 'Elemente d. Geologie,' 3rd ed. 1876, p. 373.

as the acid dissolved and disintegrated it. The deposit, when examined under the microscope, was found to consist of minute rhombohedra, some of which were considerably, and others slightly eroded, while many exhibited perfectly sharp angles and edges (Pl. XIX. fig. 6).

It seems quite possible that such a limestone might, through natural causes, become almost wholly dissolved and replaced by silica, the replacement going on gradually and keeping pace with the dissolution of the limestone, a rhombohedron becoming here and there enclosed in the siliceous matter and thus protected from further erosion. That such was the case in the Ouachita stone is rendered extremely probable, from the fact that many of the cavities have irregular boundaries, such as would have resulted from the enclosure of partially eroded rhombohedra or small groups of rhombohedra. In Pl. XIX., figs. 9 & 10, two such cavities are shown. Sometimes cavities occur which have evidently been occupied by a group of ten or twelve coherent crystals. I think it must be admitted that the forms of these cavities give evidence of erosion, rather than of arrested crystallization of the mineral which once filled them.

In the next place, let us assume that the original limestone was not a true dolomite, but merely a dolomitic limestone. Then, since calcite is more readily soluble than dolomite, it is easy to imagine that the whole of the calcite might become dissolved and replaced by silica, the latter enveloping the less readily soluble rhombohedra of dolomite. If a small amount of limestone can be replaced by silica, as in the layers and nodular bands of chert, met with in the Carboniferous Limestone, there seems no reason why, given a sufficient supply of silica in solution, thick beds of limestone should not be wholly replaced.

That it is unsafe to deny, in all cases, a detrital origin to siliceous beds associated with limestones is rendered sufficiently evident from the occurrence of thin beds of metamorphosed sandstone or quartzite interstratified with limestone at Modoc Peak in the Eureka district. This sandstone is described by Prof. Iddings as somewhat micaceous and graduating from an extremely fine-grained to a coarse-grained rock "having the mineral composition and structure of a micro-granite."[1] Judging from the figure given in his memoir, which represents a section magnified 33 diameters, the rock is a quartzite, or, as it is described, a quartz-conglomerate, of somewhat coarse texture and in no way resembling siliceous rocks of cryptocrystalline character, such as Arkansas stone, Ouachita stone, flint, or chert, none of which exhibit characters which a sandstone even of the most altered type would possess. The Modoc Peak quartzite, on the other hand, consists of rounded grains of quartz cemented by a secondary deposit of silica, and is unquestionably a sedimentary rock.

[1] 'Geology of the Eureka District, Nevada,' by Arnold Hague, Monographs U.S. Geol. Surv. vol. xx. (1892), Appendix B, by J. P. Iddings, p. 346, and fig. 3, pl. iv.

Reverting once more to the rhombohedral cavities which occur in Ouachita stone, there seems to be an additional reason for believing that they were originally occupied by dolomite and not by calcite, from the fact that the rhombohedron, when uncombined with other forms, is not common in calcite, while it is of extremely common occurrence in dolomite.

The general absence of fossils in the actual novaculites of Arkansas, although some, chiefly the ossicles of crinoid-stems, have been met with,[1] need form no barrier to the hypothesis that the rock is a siliceous replacement of a limestone, since it is common to find beds of dolomite almost or quite destitute of fossils, and, as Prof. Renard remarks, "gelatinous silica moulds itself upon objects and preserves their forms; dolomite, on the contrary, through its tendency to develop terminated crystals, tends to efface them when it becomes infiltered among organic remains."[2] Furthermore, the stratigraphical relations of the Arkansas novaculites are not incompatible with the assumption that they are the siliceous replacements of limestone; for, according to Mr. Griswold, they occur between shales of late Lower Silurian[3] (Ordovician) age in which graptolites are found, including the genera *Diplograptus* and *Dicranograptus*, both of which are abundant in the Bala series of Wales, while the former genus, if not the latter, occurs also in the black graptolitic shales of the Coniston Limestone series.

The association of the Arkansas novaculites with black graptolitic shales, and that of our own Ordovician limestones with similarly coloured graptolitic shales, is not, certainly, a proof that the novaculites are representatives of Ordovician limestones, but it is a coincidence which, to say the least, is significant.

At this stage it seems desirable to discuss the character of the siliceous grains which constitute the Arkansas novaculites.

In a paper by Messrs. A. J. Jukes-Browne and W. Hill[4] remarks by Dr. G. J. Hinde are quoted, in which he says that he "is unable to explain the causes which have produced this singular [globular] form of colloid silica, or to say why the silica of the sponge-spicules should not have passed into the more stable condition of chalcedony or crystalline quartz, as is the case with those of most other fossil sponge-beds." Here we have Dr. Hinde's statement that sponge-spicules may be found not only in the condition of colloid silica (opal), but also in the cryptocrystalline condition (chalcedony) and in the crystallized condition (quartz). This appears to indicate that the originally colloid silica of a sponge-spicule may undergo a series of changes which culminate in its conversion into quartz. May not that which happens in a sponge-spicule also occur in the silica which replaces a limestone?

[1] 'Whetstones and the Novaculites of Arkansas,' p. 133.

[2] 'Des Caractères distinctifs de la Dolomite, etc.,' Bull. Acad. roy. Belgique, ser. 2, vol. xlvii. (1879) p. 562.

[3] 'Whetstones and the Novaculites of Arkansas,' p. 205.

[4] 'The Occurrence of Colloid Silica in the Lower Chalk of Berkshire and Wiltshire,' Quart. Journ. Geol. Soc. vol. xlv. (1889) p. 407.

The late John Arthur Phillips, in speaking of the siliceous deposits at Steamboat Springs, Nevada, U.S., remarked that "the fissures, which appear to have been subjected to a series of repeated widenings, such as would result from an unequal movement of their walls, are lined, sometimes to a thickness of several feet, by incrustations of silica of various degrees of hydration, containing hydrated ferric oxide and, exceptionally, crystals of iron pyrites. This silica exhibits the ribbon-like structure so frequently observed in mineral veins, and, when examined under the microscope, is seen to consist of alternately amorphous and crystalline bands, enclosing druses lined with minute crystals of quartz."

Speaking of an older group of fissures, about a mile west of the last-named locality, he adds:—"The silica of this deposit is sometimes chalcedonic and contains nodules of hyalite; the larger proportion of it, however, although somewhat friable, is distinctly crystalline. The crystals contain numerous liquid cavities, and exhibit the usual optical and other characteristics of ordinary quartz."[1]

The foregoing statements prove, I think, quite sufficiently, that deposits of silica may pass from the amorphous into the crystallized condition, and, bearing this in mind, it appears by no means improbable that like changes may occur in the silica which replaces a limestone.

Mr. Griswold regards the siliceous grains which constitute the Arkansas novaculites as quartz. The specific gravity of Arkansas stone, however, is given by him as 2·648 or, making allowances for the "excess of weight caused by the presence of the heavier elements," 2·643. He adds that "this falls within the limits given for silica in the form of quartz ('Chemiker-Kalender' for 1888), which places the specific gravity at from 2·64 to 2·66. The specific gravity of novaculite may be a trifle lower than the average for quartz, since some air may remain in the pores of the stone and decrease its weight in water by a small amount."[2]

In order to avoid any error due to the presence of cavities, I reduced fragments of the translucent Arkansas stone to fine powder, and employing the pycnometer and distilled water at 15° C., found the specific gravity to be 2·6441. The weight of powdered stone used was 2½ grammes, and every precaution was taken to ensure accuracy. Mr. Griswold's estimate, 2·643, approximates very closely to this, but in either case it seems that the specific gravity comes rather within the range of chalcedony than of quartz. Prof. J. D. Dana gives the specific gravity of chalcedony as 2·6 to 2·64, which agrees with that of Arkansas stone, while for quartz he gives 2·653 to 2·654, and for crystals of quartz from Herkimer he cites Penfield's determination as 2·66.[3]

All of these figures for quartz are higher than those for Arkansas stone. So far, therefore, as specific gravity is concerned, Arkansas

[1] 'Ore Deposits,' 1884, p. 70.
[2] 'Whetstones and the Novaculites of Arkansas,' p. 93.
[3] 'System of Mineralogy,' 6th ed. 1892, p. 186.

stone appears to have a better right to be regarded as chalcedony than as quartz.

On p. 92 of his work, Mr. Griswold says:—"As the silica of novaculite is neither crystalline, amorphous, nor chalcedonic, it must be classed with those minerals which are structurally too fine to show distinctive characters and are called cryptocrystalline. Thus novaculite becomes a member of the same class of rocks with chalcedony, flint, basanite or touchstone, chert, and jasper, a group of rocks to which novaculite would, from its physical appearance, seem naturally to belong." This statement appears to be true. It may, however, be observed that, although this author says the silica of novaculite is not chalcedonic, chalcedony is usually regarded as one of the cryptocrystalline varieties of silica. It should, nevertheless, be noted that this evident slip of the pen is covered by the concluding portion of the passage just quoted. Again, on p. 90 of his work, Mr. Griswold states that "the remarkable fact demonstrated by the analyses is the very constant, high percentage of silica. Experiments on the solubility of the silica in caustic potash show that it is almost entirely in the anhydrous form. There would, therefore, be but little silica in the rock having the chalcedonic structure, since chalcedonic silica is partly hydrous and pretty soluble in caustic potash. Five per cent. is about the average of soluble silica in the Arkansas stones as obtained by these tests. This may seem rather high, but when it is considered that by the same tests quartz-crystals, which are supposed to be practically insoluble, give an average of about 4 per cent. of soluble silica, the conclusion is reached that the silica of the novaculite is in a very stable form. Two specimens of chert tested in the same way gave over 30 per cent. of soluble matter, most of which was silica."

The last statement is no doubt true, but cherts differ, and, in one analysis by Mr. E. T. Hardman, only a trace of soluble silica was present, while in another made by him, also of an Irish chert from the Carboniferous Limestone, the amount of silica soluble in caustic potash was merely 0·95 per cent.[1]

Mr. Griswold, on p. 91 of his work, quotes the opinions of other writers, and among them the following:—

"Mr. G. P. Merrill questions the theory of interlocking crystals to account for the grit of the Hot Springs novaculite. He says that, as a result of his own investigations, it is composed of 'a very fine and compact mass of chalcedonic silica in which are embedded widely-scattering angular grains of quartz'."[2] I agree with Mr. Merrill, but, so far as the grit of the Ouachita stone is concerned, I am inclined to think that the presence of minute grains of garnet may have a certain influence.

Mr. Griswold further says that "Dr. J. C. Branner, State Geologist, declares his disbelief in the theory that all the novaculites are metamorphosed sandstones, and suggests that the 'compact varieties

[1] 'The Chemical Composition of Chert, etc.' Sci. Trans. Roy. Dublin Soc. vol. i. (new series) p. 90.

[2] 'Mineral Resources of the United States,' 1886, p. 589.

[illegible]

Had the rhombohedral crystals been formed in the manner suggested by Mr. Griswold it seems doubtful whether they would have been so perfectly developed. Moreover, if the surrounding material consisted of already-formed quartz-grains, there would not have been the selective arrangement of grains around the rhombohedra which is so well shown, at times, in Ouachita stone. Had the rhombohedra been formed last, they would have pushed the surrounding grains aside, or have enveloped them, and of this there is no clear evidence. To my way of thinking, all points to the solidification of silica around already-formed crystals of dolomite.

If the views advocated in the present paper be correct, we have here, in these Arkansas novaculites, a case of metasomatosis on a large scale. Mr. Griswold states that the novaculites "occur in massive strata, usually presenting plane surfaces and having only thin layers of shale interbedded. Five or six hundred feet is the common thickness of the novaculite formation, which generally includes some flinty shales and soft shales or sandstones. The novaculites proper are the prominent members of the formation, however, and occur in massive beds from a few inches to twelve or fifteen feet in thickness. When thinner than about four inches the beds generally lose their novaculite character and are more like flinty shale."[1]

There seems nothing improbable in beds, of the thickness above cited, being wholly replaced by silica. Prof. Hull states that "in the south-western districts of Tipperary, Limerick, Kerry, and Cork, the principal masses of chert occur at the top of the limestone, immediately below the shales of the Yoredale series, and sometimes are so abundant as almost completely to replace the limestone itself. ....At the foot of the ridge west of Carlow, the limestone is completely replaced by masses of greyish chert in thin layers, and over thirty or forty feet in thickness."[2]

If the beds of novaculite be a siliceous replacement of limestone-beds, it by no means follows that their thickness indicates the former thickness of the limestones, since the removal of limestone may have been greater by far than the amount which has been replaced by silica.

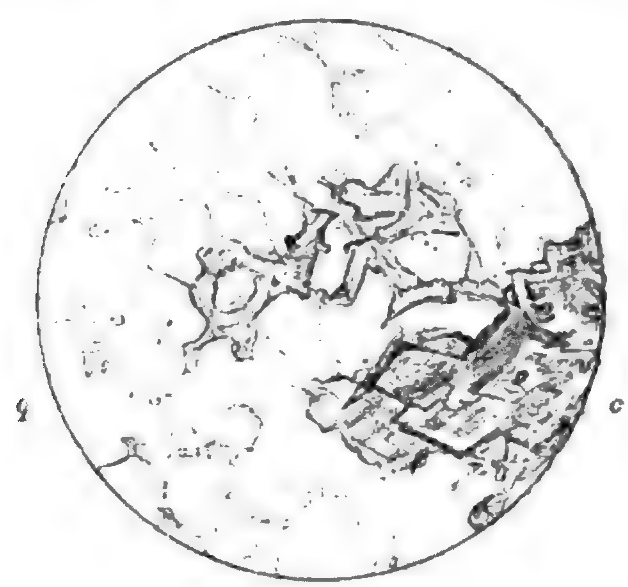
In connexion with the rhombohedral cavities, it may be pointed out that the component rhombohedra of a dolomite are not all of the same size, as shown in Pl. XIX. fig. 6, although there is a general uniformity in this respect. Some of the rhombohedra are occasionally 15 or 20 times as large as others, and these larger crystals would take longer to dissolve and would probably form a fair proportion of the residue which ultimately became imprisoned in the silica. That many of the dolomite-crystals were more or less eroded is evident from the irregular forms of some of the cavities in the Ouachita stone.

[1] 'Whetstones and the Novaculites of Arkansas,' p. 94.
[2] 'On the Nature and Origin of the Beds of Chert in the Upper Carboniferous Limestone of Ireland,' Sci. Trans. Roy. Dublin Soc. vol. i. (new series) p. 75.

In this paper the belief has already been expressed that structural gradations might be traced from Arkansas stone to rocks which would generally be recognized as quartzites, but it remained to be shown whether such a structural series could in each instance, or in every grade, be referred to a similar origin: namely, whether, at the two extremes of such a series, rocks could be found which could be proved to be siliceous replacements of limestone.

The example which we shall next consider will, I think, help to do this, since, in point of structure, it approaches more nearly to a quartzite than any limestone-replacing rock with which we have yet had to deal. The specimen approaching nearest to quartzite which has hitherto been mentioned is the pebble from Purtiall. This seems to form a link between what we recognize as the cryptocrystalline and microcrystalline conditions. That these conditions have no distinct individuality is, I think, almost certain, since they appear to depend upon the size of the crystals or grains in relation to the thickness of the section, while the dark lines, which seem to be the sinuous outlines of interlocking grains, when the section is examined between crossed nicols, are seen to wander and frequently form irregular contracting and expanding rings as the section is rotated. That this phenomenon is due to compensation, brought about by the squamose overlapping of small crystals or crystalline grains, which react upon one another as diminutive quartz-wedges, seems highly probable.

Fig. 1.—*Auriferous quartzite from Nondweni, Zululand.*
(Ordinary light.)



× 140.

q = quartz. *c* = calcite.

Some time ago several specimens were sent me from Zululand by my late sister-in-law, Mrs. Jenkinson. They were from the Zululand Gold-fields, and bore no other label; but Mr. Graham Jenkinson, during a recent visit to this country, was able to give me the locality

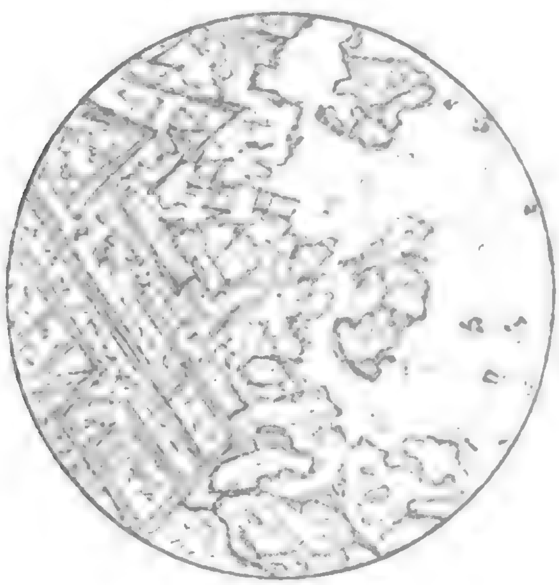
of certain bluish-grey, auriferous quartzites, which he recognized as similar to those occurring at Nondweni.

A section cut from a small but rich fragment shows, when examined under the microscope, that the rock is a quartzite, but that, in addition to gold, it also contains a very considerable amount of calcite. The quartz appears in polarized light as a mosaic of crystals and irregular grains, which give positive uniaxial figures in convergent light. The calcite occurs in irregular patches, strings, and finely-shredded particles. The patches sometimes show very distinct rhombohedral cleavage. Frequently small crystals of quartz occur within, or irregularly mixed with, the calcite, and occasionally the latter mineral appears as if squeezed between the crystals of quartz (fig. 1, p. 388).

Careful examination of the section leads to the conclusion that the calcite does not form true veins in the quartzite, since the sharp boundaries which almost invariably characterize veins are not present. The calcite appears shattered, frayed, or shredded out where it comes into contact with the quartz, suggesting the disintegration of the former by a solvent (fig. 2). It might be urged that both the calcite and the quartz crystallized simultaneously, but I can see no proof of this, appearances pointing rather to the disintegration of pre-existing calcite and infiltration of silica, which crystallized out as quartz.

Fig. 2.—*Auriferous quartzite from Nondweni, Zululand.*
(Ordinary light.)

c



q

× 140.

q = quartz. c = calcite.

The gold occurs in irregularly-shaped particles, sometimes apparently in octahedral crystals, and it is mainly situated in the calcite. In some cases, however, it lies partly in calcite and partly in quartz, while, to a small extent, it is disseminated in the quartzose portions of the section.

It would appear, then, that the gold originally occurred in a bed

of limestone, the latter having since been in great part dissolved and replaced by quartz, which has taken up some of the gold it contained. The quartz envelops a residue of the limestone, the marginal portions of the included limestone-patches showing that the process of disintegration was going on when it was arrested by the solidification of the silica (fig. 2, p. 389).

The brisk evolution of bubbles when a fragment of the rock is placed in dilute hydrochloric acid indicates that the carbonate is, in this case, not dolomite, but calcite. A drop of the solution, when treated with chloride of ammonium and ammonia, and phosphate of soda added, yields a few microscopic crystals of the ammonio-phosphate of magnesia; but this magnesia is doubtless derived from a pale greenish substance, which is present here and there in the calcite, and which may be regarded as probably some variety of chlorite.

We have, then, in this rock a case in which a quartzite of comparatively coarse microscopic texture has originated as a siliceous replacement of a limestone, just as I believe the fine-grained Ouachita stone and the still finer Arkansas stone are the siliceous replacements of dolomites or of dolomitic limestones.

Although the association of gold with calcite is unusual, it is by no means unknown. Thus, the late John Arthur Phillips, in describing the St. David's Lode (Clogau Mine, North Wales), says:—"It is chiefly composed of quartz and calcite, the latter mineral sometimes forming masses of several feet in width; where the calcite assumes the appearance of a friable and granular marble, it not unfrequently contains gold, but when, on the contrary, it becomes foliated or is coarsely granular, that metal appears to be entirely wanting."[1]

It may be that the evidence adduced in support of the views advanced in this paper will not prove conclusive to all minds. Those views were, in fact, laid before this Society in a former paper,[2] to which this may be regarded as a sequel. It is but a very imperfect sequel, since I hoped to have been able to discuss the differences between concretionary and residual limestone-nodules, but, in the absence of suitable material to work upon, this portion of the subject could not be dealt with.

In conclusion, I am anxious to express my profound appreciation of Mr. Griswold's work, although I have occasionally taken the liberty to criticize it. To do it justice would, indeed, be no easy task. His book is a mine of facts, a storehouse of well-arranged and valuable information. Upon several of the points on which I have ventured to differ from Mr. Griswold, he has himself expressed doubt, and I have therefore felt the less diffidence in attempting to explain that which seemed obscure.

[1] 'Ore Deposits,' p. 203.

[2] 'On the Dwindling and Disappearance of Limestones,' Quart. Journ. Geol. Soc. vol. xlix. (1893) p. 372.

[Postscript.—On perusal of the remarks made by Dr. Hinde, in the discussion which followed the reading of this paper, it would appear that, in stating the thickness of the novaculite-formation with its shales and sandstones, he lost sight of the fact that the novaculites themselves occur in beds which, according to Mr. Griswold, range from only a few inches up to 15 feet in thickness. There is nothing improbable in the erosion or replacement of limestone-beds of such dimensions. With regard to the question: What became of the limestone? it can only be answered that, if once there, as I believe it to have been, it was carried away in solution: the usual fate of limestones. As for the silica, it is difficult to express any decided opinion concerning the source from which it was derived. It may have been deposited from thermal waters.—May 23rd, 1894.]

EXPLANATION OF PLATE XIX.

Fig. 1. Arkansas stone. × 380. Crossed nicols.

Fig. 2. Flint-pebble, Thames Gravel. × 380. Crossed nicols.

Fig. 3. Ouachita stone. The dark patches are spaces due to cavities, often of distinctly rhombohedral form, once occupied by crystals, probably of dolomite. × 140. Crossed nicols.

Fig. 4. Siliceous rock, approximating to quartzite and containing rhombohedral crystals of a carbonate, probably dolomite. From conglomerate. Purtiall, Deccan, India. × 140. Crossed nicols.

Fig. 5. Magnesian limestone, occurring in the Carboniferous Limestone Series. Cumberland Cavern, Matlock Bath, Derbyshire. × 140. Ordinary light.

Fig. 6. Rhombohedra of dolomite derived from the preceding specimen by the action of dilute hydrochloric acid. × 140. Ordinary light.

Fig. 7. Pebble from conglomerate, Purtiall, India. Edge of the same section as that represented in fig. 4. × 380. Crossed nicols.

Fig. 8. Auriferous quartzite, Nondweni, Zululand. Edge of quartzose portion of section. × 380. Crossed nicols.

Figs. 9 & 10. Forms of cavities in Ouachita stone, once occupied by partially eroded crystals of dolomite. × 75.

Discussion.

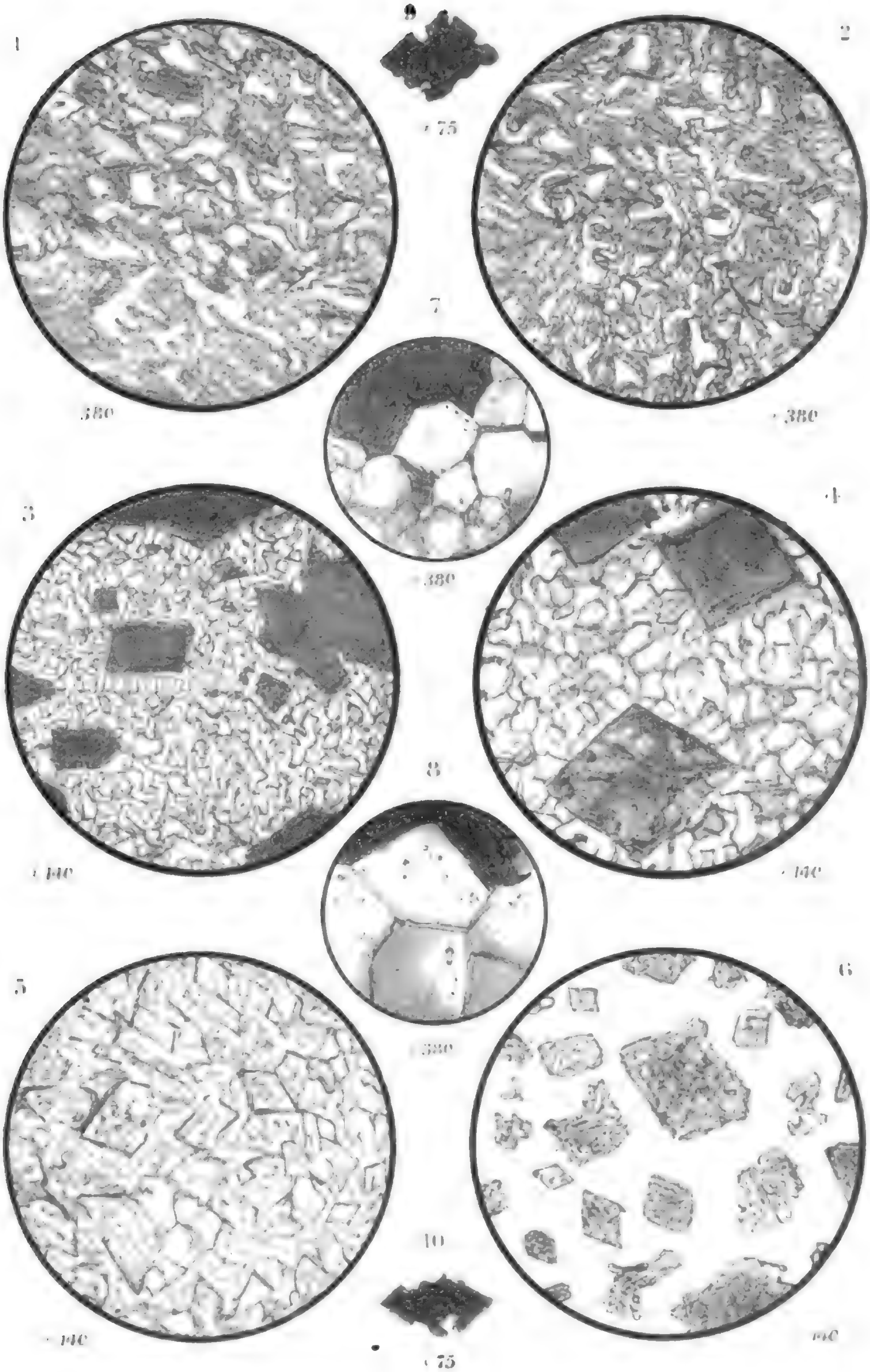
Dr. G. J. Hinde complimented the Author on the ingenuity of his explanation of the origin of the Arkansas novaculite-rocks, but failed to see that there was any evidence for his fundamental assumption that these rocks were originally limestones or dolomites which were now replaced by silica. Taking into account that the novaculites were over 500 feet in thickness, and that they were interbedded with shales and sandstones, it might reasonably be asked what had become of the limestone of which they were originally supposed to be formed, and also whence the silica had originated which was stated to have replaced the limestone?

The speaker did not agree with Mr. Griswold that the novaculites were produced by simple sedimentation of fine fragmental silica; but he considered that their structure of cryptocrystalline silica, and their resemblance to Chalk-flints in microscopic characters, which Mr. Rutley had pointed out, indicated that, like these latter,

they might have had an organic derivation. Moreover, in the beds of Carboniferous chert from Ireland, Belgium, Yorkshire, Wales, etc., and in the cherts of the Durness Limestones (sections of which were exhibited), there were numerous rhombohedral crystals of calcite, the same as in the novaculites, and they also resembled these in other respects. As these cherts had been proved to be derived from the siliceous remains of sponges, it might well be supposed that the silica of the novaculites had a similar origin. It was true that no siliceous organisms had as yet been found in the novaculites, but this might arise from imperfect observation, or it might be that the changes which had taken place in the rocks had obliterated them.

Prof. HULL remarked that the chert-beds of the Upper Carboniferous Limestone of Ireland, referred to by the Author, and described in the joint memoir by the late Mr. Hardman and himself, were composed of variable proportions of carbonate of lime and silica, and also contained silicified shells, corals, and crinoids—animal structures that must primarily have been formed in carbonate of lime: thus proving that the rock had originally been to a great extent a limestone. Along with these structures were numerous spicules of siliceous sponges, recognized in the thin slides by Dr. Hinde. But the rock described by the present Author, so far as he had been able to gather, was of quite a different character from these Carboniferous chert-beds. It was a solid quartzite, without evidences of having contained marine calcareous organisms; and however ingeniously the Author had succeeded in showing, by means of his researches in the laboratory, that a limestone might be changed into a quartzite, he (the speaker) feared that without some better evidence of so remarkable and fundamental a change in the composition of the Arkansas rock described, Mr. Rutley's views could scarcely be accepted.

The AUTHOR, in reply to Dr. Hinde's remarks, stated that he had purposely refrained from expressing any opinion concerning the source from which the silica of the novaculites had been derived. Dr. Hinde was doubtless correct in assuming that the silica of chert was frequently composed, at least in part, of the remains of sponges. He had not detected any sponge-spicules in either Arkansas stone or Ouachita stone. He also briefly alluded to the observations of Prof. Hull.



Frank Rutley del. F H Michael lith. Mintern Bros imp.

NOVACULITES, QUARTZITES, AND DOLOMITES

25. LANDSCAPE MARBLE. By BEEBY THOMPSON, Esq., F.G.S., F.C.S. (Read March 7th, 1894.)

CONTENTS.

I WAS led to a study of the structure and origin of the so-called Landscape Marble, or Cotham Stone, through reading an article in the Geological Magazine for 1892, p. 110, by Mr. H. B. Woodward, entitled, 'Remarks on the Formation of Landscape Marble.' To that article I am much indebted for information as to the general characteristics of the stone, and its mode of occurrence.

The first published description of the Landscape Marble occurs in a work by Edward Owen, the title of which is 'Observations on the Earths, Rocks, Stones and Minerals, for some miles about Bristol, and on the Nature of the Hot Well and the Virtues of its Water'; the date on the title-page being 1754. The name 'Cotham Stone' was applied to the Landscape Marble because it was quarried, with other material, near Cotham House, on the northern side of Bristol, but Owen did not give it this name; he merely adopted the appellation by which it was already known in that part of the country (*op. cit.* p. 164).

At the time of Owen the Cotham Stone was chiefly known by and valued for its peculiar, corrugated, upper surface, 'rustick' so-called, though some cut and polished specimens were to be found framed in the houses of 'the gentlemen of the neighbourhood.'

For convenience of reference, I shall number the descriptive paragraphs throughout this paper.

I. GENERAL DESCRIPTION OF THE LANDSCAPE MARBLE.

1. It is a hard, close-grained, argillaceous limestone, which breaks with a fracture almost as conchoidal as flint; and it takes a moderate polish.

2. It shows no distinct evidence of concretionary origin, although concentric layers will sometimes flake off the upper surface.

3. *The upper surface* is often much wrinkled, and the irregularities appear to correspond with the original planes of deposition, for when a layer flakes off it follows these irregularities. The wrinklings

on the surface are often curiously interlaced, giving rise to the so-called 'rustic-work' for which the stone was chiefly quarried. Owen speaks most enthusiastically of the 'rustick' thus:—"When I have viewed the whole thus nearly, it appeared not a piece of common rustick, but an imitation of something much more elegant. The depths of the hollows between the rising parts is varied, and their form different, in so strange a manner, that no two are at all alike: and the waving and curdlings of the surface in the raised parts is such, that every one of them seems a piece of rustick in miniature, the whole surface being formed, like that of the mass, into risings of the most elegant kind, and irregular hollows between them" (p. 166). Owen also refers to the scaling (p. 167).

4. *The interior of the stone* is characterized by dark markings, which pervade the stone between certain limits, and have much the appearance of foliage.

The markings rise from a more or less stratified base, spread out as they rise, and terminate upwards in the wavy banded portion of the limestone; the whole varying from 1 to about 9 inches in thickness.

As the markings are disposed more in a vertical direction than laterally, in order to show them the stone is usually cut and polished at right angles to the stratification.

5. *Two landscapes* are shown in some specimens, one above the other, but each arising from a distinct dark layer. A very fine specimen with a double landscape is to be seen in the Museum of Practical Geology, Jermyn Street.

II. Specific Description of the Landscape Marble.

Under this head I propose to describe more minutely the characteristics of the specimens in my own possession (though I believe them to be quite ordinary examples), because some important points of structure do not appear to have been noted by previous observers.

6. *The whole thickness of the stone may be regarded as made up of three distinct portions*, the upper and lower being striated and the middle irregular, through the interposition of the arborescent markings (see figs. 1 & 2, pp. 395, 397), and in the specimen that I shall particularly refer to, fig. 1, the general curvature of each layer, as well as the striæ in it, is just about the same, the inner edge being an arc of a circle of about $4\frac{1}{4}$ inches radius, and the outer edge, approximately, an arc of a circle of $7\frac{1}{2}$ inches radius.[1]

7. *The lower portion of the stone* is about $1\frac{1}{4}$ in. in thickness, and at first looks as though very sharply divided into two by difference of sediment, and a line of cleavage; neither of these surmises, however, can be retained after a microscopic examination.

The lowest (*A*) is light yellowish-brown in colour, and longi-

[1] Mr. H. B. Woodward observes that the lower surface of the limestone is even, though sometimes in small masses of the rock it is gently curved.

tudinally striated with thin, darker brown marks. This is rather less than ½ inch thick.

The next portion above (*B*) is about ¾ inch thick, of a grey colour mostly, and is longitudinally striated with darker, almost black marks.

The striæ in *A* and *B* vary in distinctness and distance from each other, but average about 20 to the inch.

8. *The middle portion of the stone* is that part where the characteristic arborescent markings occur, which it is the special object of this communication to explain.

At the base is a dark layer (*C*) conforming in general curvature with the layers below, but extremely irregular in structure, the upper part being very jagged (*the hedge*).

Above the last, but springing from it, are the more decided arborescent markings (*D*), which may rise in the form of a single stem and then spread out (*trees*) or may spread out at once (*shrubs*).

Between the arborescent parts there is a light-coloured matrix (*E*), striated, but in a very erratic manner, so that the imaginative eye may see clouds, mountains, lakes, etc. Amidst all the confusion here, however, there is uniformity in one thing, and this is most important: the striæ of the matrix are always directed upwards near the dark markings, and dip downwards between them.

This part of the stone may be taken as 1½ inch in thickness.

9. *The upper portion of the stone* greatly resembles the lower in change of colour towards the outside, and in being striated, but the uniformity of curvature has evidently been interfered with from below and from above, for the striæ rise over the arborescent markings and sink between them, and this is almost exactly what the outside of the stone does.

Just above the termination of the arborescent markings is a layer, *F*, which is more generally dark, and more obscurely striated than any other part.

Above the last, in the part marked *G*, the striations become again more distinct, but of a different colour, light yellowish-brown, as at the bottom.

The thickness of the upper portion of the stone, *F* and *G*, varies from ½ to ¾ inch.

III. Its Microscopic Characters.

10. "*The rock is mainly composed of extremely fine granular calcite*, and contains a few very small grains of quartz. In the part which shows the characteristic markings there are patches of clear and sometimes coarse-grained crystalline calcite." [1]

11. *The arborescent markings and the striæ* are composed of a form of carbonate of lime which takes a higher polish than the mass of the stone. In the specimen shown in fig. 1 (p. 395) they are entirely composed of *coralloidal aragonite*, whereas in the other (fig. 2, p. 397)

[1] J. J. H. Teall, quoted in H. B. Woodward's paper, p. 113.

Fig. 5.—Landscape Marble. (Natural size.)

they seem to differ from the matrix only in being finer grained. In all cases the outer boundary of the dark markings seems to be decidedly darker than the central portion.

12. Other points brought out by the microscope are these:—The dark markings, where composed of aragonite, are nearly uniformly coloured throughout, except at the outer boundary where contiguous to the granular calcite; whereas in the other specimen (fig. 2, p. 397), where they still retain much of the granular structure, they are spotted all over with darker patches, as dark as the outer boundary.

The outer striated parts of the stone, which in one specimen are of a different colour (see 7 & 9),[1] are exactly similar to the darker striated portions contiguous to them, except in colour.

The change of colour is in the compact aragonite, and not in the granular calcite.

The two colours, grey (inside) and yellowish-brown (outside), seem to be very sharply defined, and to follow the striæ when the stone is viewed by the unaided eye: under the microscope this is seen not to be the case, the change in colour is gradual, and the striæ cut indifferently through grey and brown.

13. *Thin veins of calc-spar* in larger crystals are found, in what are considered inferior kinds of Landscape Marble, and they may cross the stone or follow the striæ. These may often be seen quite readily without the microscope. Edward Owen remarks (p. 180) that these veins are broadest towards the bottom, and narrowest towards the top. This is the case in my specimen; indeed, the most prominent crack does not extend far into the arborescent markings (see *SS*, fig. 2).

IV. Its Chemical Characters.

14. The stone is violently attacked and rapidly dissolved by dilute hydrochloric acid, with the exception of a small quantity of brown argillaceous matter.

The aragonite dissolves more rapidly than the granular calcite, thus soon producing a very uneven surface.

15. The stone consists chiefly of *calcium carbonate*, but the solution in hydrochloric acid also contains *iron*, *aluminium*, *manganese*, *magnesium*, and a little *phosphoric acid*.

In addition to these there is the *argillaceous matter* and the *quartz*, which are insoluble. By washing the former of these, and examining it under the microscope, a few grains of the latter may usually be found.

It is also tolerably certain that there is some *carbon* associated with the darker markings, to which in fact the colour is due, for the stone is bleached on ignition. A white spot may be produced in a

[1] Numbers within parentheses, here and elsewhere in this paper, refer to the numbered sections of the description.

few seconds by directing a jet of flame on to the dark part by means of a blowpipe.[1]

V. Its Mode of Occurrence.

16. *The stone occurs in isolated and lenticular masses* which are sometimes less than 1 foot across, sometimes 3 or 4 feet. A stone some 2 feet in diameter or length is usually 8 or 9 inches thick (Edward Owen, p. 172).

The stratigraphical equivalent of the Cotham Stone occurs in other places as a fairly persistent layer; where this is so it is banded and evenly bedded, but the arborescent markings and crinkly upper surface are wanting. Between the ordinary banded limestone and the distinctly arborescent types many intermediate varieties may be found.

17. *The stone is not very continuous, even where it takes the bed form*, although met with more or less over a large area. It may be that at some places the bed is present, but not identified, because of the absence of the arborescent markings.

18. *The position of the Cotham Stone is in the Rhætic Beds*, at or near the junction of the black *Avicula contorta*-shales with the overlying beds of White Lias, that is, between dark argillaceous sediment and almost pure calcareous mud, though in some localities a few inches of dark clay may be found above the stone.

VI. Theories as to the Origin of the Landscape Marble.

Edward Owen, who first described the Landscape Marble, thought that the arborescent markings were produced by the escape of imprisoned air. Some have thought that gaseous emanations from the black mud of the *Avicula contorta*-shales had something to do with the peculiar structure of the marble. Others again have considered that infiltration of dark mineral matter would account for it.

Mr. H. B. Woodward's recent explanation of the origin of the Landscape Marble[2] is as follows:—"It appears to me that the arborescent markings were produced during the consolidation of the stone, and more particularly by the shrinking of its upper portions. In this way, and while the mud was still in a more or less pasty condition, one or more of the dark films in the banded mass were disarranged and dispersed in arborescent form in the slowly setting rock .... It may be that the production of the isolated masses of rock, with their irregular upper surfaces, was attended by some pause in the deposition of sediment, and by exposure of the layers to the sun's rays . . . The process of formation of the Landscape Marble seems to me to have been mainly mechanical, although,

[1] Since writing the above I have read the following passage:—'Mr. Allan Dick, who has kindly examined a specimen of the Cotham Marble, tells me that dark portions of the stone are not due to the presence of manganese- or iron-ores, but are probably due to carbonaceous matter.'—Mem. Geol. Surv. 1893, 'The Jurassic Rocks of Britain,' by H. B. Woodward, vol. iii. p. 31.

[2] Geol. Mag. 1892, pp. 112, 114.

as might be expected, there is evidence also of chemical change. In attributing the corrugated surfaces to the shrinking of the calcareous mud, I may have appealed too strongly to mechanical causes, as apart from the obscure processes of segregation, or even of concretionary action."

A perfect explanation of the origin of the Landscape Marble should, of course, account for *all* the characteristics enumerated (1 to 17); but if this be impossible we must remain content with one that will account for the greater number, without being obviously at variance with any. Let us first of all clear the ground of those explanations or theories, or parts of theories, which are at variance with the known characteristics of the stone, so that the explanation which I shall presently offer may be less encumbered.

The escape of imprisoned air.—Edward Owen's theory cannot be entertained as an explanation, even if we give 'air' the wider signification of 'gas,' which it may have had to Owen in 1754, for gas could not have been imprisoned in a fine soft mud such as this stone must have been when forming; nevertheless, after reading Owen's description, I am inclined to think that he had a clearer conception of the method of formation than he was able, through lack of chemical knowledge, to express.

Gaseous emanations from the black mud of the Avicula contorta-shales (18) must also be discarded as a theory, for the simple reason that in most specimens, perhaps in all, the lower portion of the stone (the part that rested on these shales) is quite free from the black arborescent markings, and in place of them are horizontal ones alternating with other sediment (7). The not uncommon presence of two landscapes (5) is also quite inexplicable by this theory.

Infiltration of dark mineral matter cannot be accepted as a cause of the arborescent markings, because they spread out upwards and not downwards, and because they are bounded, both above and below, by the same dark matter in regular bands lying in an approximately horizontal position (4–9), and also because the markings are much too large, and much too distinctly and evenly bounded (11). For the same reasons, and others, *mere staining* is quite out of the question.

Shrinkage of the stone, whether before or after consolidation, cannot alone be admitted as a cause of the arborescent markings, though for other reasons we must admit considerable shrinkage.

Shrinkage after consolidation could not have caused it, because then there would be an absence of fluid or semi-fluid matter such as must be postulated to account for one kind of mineral matter becoming so irregularly mixed with another.

That shrinkage before or during consolidation cannot be admitted *as a cause* is equally certain, because in such a fine-grained rock as this (1, 10) the interspaces between the particles (or crystals, if they then existed) of the matrix would be much too small to admit of the intrusion of such comparatively large masses of foreign

coloured matter.[1] The darker matter must necessarily have been more fluid than, and quite as finely constituted as the matrix to have been displaced by and dispersed in the latter, and then a kind of marking to which the term 'dendritic' is usually applied would have resulted. To me it seems impossible that one layer can be fluid enough to be squeezed into another, and yet coherent enough to move only in masses.

Again, if pressure were the sole cause, why should not the dark matter have been squeezed downwards below its point of origin as well as upwards (4–9), and why were not the thinner horizontal bands of dark matter also displaced (7, 9), or at least bent irregularly, whilst the shrinkage was going on?

VII. Mode of Formation of the Landscape Marble.

Perhaps it will be well to say here that I commenced my investigation of Landscape Marble with the preconceived idea that its peculiar characteristics were due to interbedded layers of vegetable matter, which continued to decompose and evolve carbonic-acid gas and marsh gas after its deposition; and that where a layer of extra thickness occurred the decomposition continued whilst a thickness of several inches of new sediment was laid down, with the result that arborescent markings were produced along the lines taken by the escaping bubbles. The excessively wrinkled upper surface of the stone seemed to necessitate a central portion capable of considerable shrinkage, and organic matter provided such a material.

A careful examination of all the characteristics of the stone, and some experiments aiming at its artificial reproduction, have confirmed the main idea, but have caused me to modify the explanation of the formation of the crinkled upper surface.

The rock was without doubt a sedimentary one (1, 4–9, 16, 17); it occurs in the midst of sedimentary rocks (18), and is intimately associated with a fairly persistent bed (16), although it might at times appear to be merely a concretion (2). The flaking off sometimes observed is due to original difference of sediment (3), and to the present different physical characters of the light and dark matter respectively; it occurs in the nearly horizontal lower layers as well as in the upper undulating ones (10, 11, 12).

It has undergone considerable change since its deposition, both physical (1, 3–9) and chemical (10–13), at least so far as the reconstruction of some of the crystallizable matter and oxidation of the outer layers in some specimens (7, 9) are borne in mind, without as yet considering the changes in the organic matter connected with the formation of the arborescent markings.

The conchoidal fracture of the stone (1) is a characteristic usually observed in fine-grained limestones, I believe, and does not, therefore, need special treatment.

[1] One of the single stems, without bifurcation, I have found to be more than $\frac{3}{4}$ inch long, and from $\frac{1}{16}$ to $\frac{1}{8}$ inch wide.

While the stone now called Landscape Marble was being formed there were very frequent alternations of light-coloured and darker matter deposited (7–9), and occasionally a dark layer of greater thickness than usual was formed, with the apparently inseparable accompaniment of arborescent markings above it (4, 8); if two such unusually thick layers occur there are two landscapes (5). Three landscapes may and do occur, but I have never seen a specimen.

The connexion of the arborescent markings with the dark layer from which they spring may, therefore, be regarded as beyond doubt, though if other proof were needed it would be found in the facts that they are of the same colour; of the same lustre (11), which is different from that of the matrix; and of the same chemical composition and crystalline form (11, 12).

That the arborescent markings originated from the dark layer, and not the latter from the former, must be obvious, from the following considerations:—All the markings start from the dark layer, whereas they finish anywhere, some only at half the height of others (see fig. 1, p. 395); the narrowest portion is downwards (4), whereas the opposite would be the case if the source had been above. But the most conclusive reason of all is the invariable lifting of the matrix contiguous to the dark markings (8).

The material of the dark bands and arborescent markings must have been either more plastic than the matrix, or of a less dense matter, to have allowed itself to be squeezed or lifted from its original bed through overlying layers (4, 8). I think it was actually both less dense and more fluid, for not only was it lifted through comparatively heavy inorganic material, but when it reached the surface it spread out in all directions, and produced exceedingly thin films of dark matter which completely roofed in the arborescent marks (9); see also fig. 1, p. 395.

The dark matter could not have been a coloured fluid merely, for although the matrix of the stone admits of staining, since it can be bleached by weathering (7, 9, 12), no staining has occurred, the outer boundary of the markings being sharply defined; in fact, the markings are distinctly darker along their outer boundary than anywhere (11), except the spots in the spotted form (12), whereas with ordinary staining the reverse would be the case.

It would appear, therefore, that the original material of the dark markings was semi-fluid, and contained finely divided dark matter, such as carbon or oxide of manganese, disseminated through it.

That carbon and not oxide of manganese (15) was the darkening matter appears tolerably clear, for the following reasons:—The dark parts are readily bleached by a blowpipe flame (15); in one specimen darker spots are very unequally disseminated through these parts (12); I have experimentally shown that bubbles of carbonic-acid gas will lift and disseminate finely-divided carbon from a layer covered with fine sand, whereas they would not lift oxide of manganese; and, lastly, carbon fits in much better with all

the other evidence as to an organic origin for the dark layers and marks.

The mammillated or corrugated upper surface of Landscape Marble (3) is so distinctive that it must evidently require an explanation dependent upon the other peculiar characteristics; ordinary desiccation is quite inadequate, otherwise we should much more often meet with similar characteristics in other stones. At first, I thought that the excessive wrinkling of the upper surface of the stone was due to exceptional contraction of the interior, and this an interior composed partly of vegetable matter would give; but I was quite conscious that this was not all the truth, because it did not sufficiently account for the wrinkling occurring only on the upper surface.

Since I commenced writing this paper I quite accidentally obtained a very near approach to the appearance of the 'rustick' on Landscape Marble, thus:—Some zinc dust was mixed with copper sulphate (Zn.Cu. couple); after some time the compound produced was washed and left suspended in distilled water—I say suspended, for, although prepared more than a month ago, it has never really settled, but constantly occupies much more room than it would do as a dry solid, leaving some water at the top quite clear. This preparation has slowly, but continuously, evolved hydrogen, but to disengage the bubbles, which are below the surface of the suspended matter, a slight shake is necessary. The particular point, however, is this, that whenever the vessel has been left quiet for a day or two the upper surface of the solid is covered with hills and hollows greatly resembling the upper surface of Landscape Marble. When the flask is shaken, bubbles of gas escape, the hills collapse, and gradually an even surface is produced again. The bubbles of gas do not generally escape from the hillocks, but rather from between them; nevertheless, when the gas has escaped the contiguous hillocks fall, showing that the elevation of the surface of the solid was due to the upward pressure of the hydrogen.

I consider, therefore, that the upper corrugated surface of the Cotham Stone is chiefly due to the upward pressure of the same gases that produced the arborescent markings, after their escape had been prevented by increasing coherence or greater thickness of the upper layers of sediment.

The fact that the arborescent markings rise where there is a hillock, and that they are absent altogether under the larger depressions, at least in my specimens (see fig. 1, p. 395), renders the above explanation all the more plausible, though shrinkage must also be given its just due (9).

The curvature of some specimens of Cotham Stone is evidently a later production than the stone itself, for it affects all the layers alike (6), and so need not detain us much. Since the curvature is sometimes very irregular (see fig. 2, p. 397), it seems that it is most likely due to earth-movements.

The physical constitution of the Cotham Stone as revealed by the microscope does not permit, perhaps, of so certain an explanation as

the macroscopic characters, but, in conjunction with the chemical composition, it forms a study of much interest.

The fine granular calcite (10) may have been an actual deposit of detrital matter from adjacent calcareous lands, or a chemical precipitate from warm shallow waters. I incline to the latter belief for these reasons: (*a*) the limestone is fairly pure; (*b*) the carrying power of water which deposited such frequent alternate and very thin beds of vegetable matter must have been insignificant.

The presence of small grains of quartz (10, 15) does not constitute any great obstacle to this idea, because they, together with the argillaceous matter, may have been brought with the vegetable matter.

The formation of the coralloidal aragonite, the presence of which in one of my specimens so accurately coincides with the limits of the arborescent markings and dark bands, is a problem of much interest, and seems to point to organic matter as being sometimes a determinative agent in the crystallization of calcium carbonate.

The superior lustre of the arborescent markings and dark bands is most obvious if a polished specimen of the stone be held before a window, so that the light falls upon it very obliquely; indeed, they have then quite a metallic appearance, so much so that at first I looked for a sulphide of some metal. In one specimen the higher refractive power of aragonite accounts for its higher reflective power than the calcite matrix, but its greater compactness or non-granular texture may materially contribute to that result. In another specimen other causes must be sought (see below).

The darker colour of the nearly transparent aragonite might be due to its greater transparency if surrounded by opaque matter. This assumption, however, is negatived by the fact that the aragonite is really darkest where thinnest, that is, at the outer boundary (11). The darkness is therefore due to contained darkening matter—carbon. Quite apart from the fact that it is difficult to account for the even dissemination of a heavy substance like oxide of manganese in a vertical direction, the amount of manganese indicated by a qualitative analysis seemed rather too small to fit the explanation.

In the specimen of stone (fig. 2, p. 397), where the presence of aragonite in the dark markings is not obvious (12), the markings are quite as lustrous, or even more so; this may be due to a darker background of carbonaceous matter (12), to the finer polish which the finer granules give, or to the actual presence of some aragonite; possibly to all three causes, more or less.

Whether aragonite was imperfectly formed in the first instance, or has since been more or less degraded to calcite, seems a rather unprofitable speculation, as the evidence appears equally favourable to both theories; the excessive amount of unoxidized carbon pointing to the former, and the greater instability of aragonite pointing rather to the latter explanation.

The alteration of colour in the outer layers of some specimens appears to be a fairly common characteristic (7, 9, 12), for Edward Owen several times refers to it (*op. cit.* pp. 169, 175); though whether they are like this when first quarried or only become so on exposure I cannot say: one would think the latter is the case. The only interest attaching to this very common feature is that, under the microscope, the change of colour appears to be confined to the aragonite; at least, it is so in my specimen (fig. 1, p. 395). From this it would appear that any carbon present was slowly oxidized, and iron and manganese only left as colouring matter, a sufficient amount of these being present to colour the nearly transparent calcium carbonate a light brown, although not enough to colour the thin, opaque, white layer produced on ignition. There is no difficulty in supposing these changes to have occurred, for the discolouration some distance into the stone (7, 9, 12) shows the possibility of water and dissolved gases penetrating thus far.

The thin veins of calc-spar (13) may have been produced at any time posterior to the formation of the bed by ordinary desiccation and subsequent infiltration.

The chemical composition does not suggest anything of importance besides what I have already dealt with; the phosphoric acid found in the stone may, or may not, all have been introduced by the plants. Some of it almost certainly was.

VIII. Experiments made to reproduce the Characteristics of the Landscape Marble.

Supposing the explanations just offered of the origin of the peculiar features of Landscape Marble to be true, it seemed probable that they might be reproduced artificially. I therefore made the following experiments.

(1) A rather wide glass tube was plugged at one end with a mixture of fine sand and plaster of Paris; over this was spread a layer of ground chalk rendered dark by admixture with oxide of manganese, and on the top of all some very fine sand. The whole was sufficiently porous to let water through gradually. On pouring dilute hydrochloric acid into the tube effervescence occurred in the middle dark layer, and bubbles escaped from the top, but there was no noticeable rising of the dark layer to follow the bubbles of carbonic-acid gas. It was not possible to get out the triple plug without breaking it up, and another plan was adopted.

(2) The same materials were used as in the previous experiment, but they were placed in a small flower-pot. The whole experiment was conducted more slowly, and after its probable completion a solution of carbonate of soda was run through, with the idea that some calcium carbonate would be re-formed, which would help to fix any characters that had been developed. On taking the material out of the flower-pot, I noticed (*a*) that the layers separated the one from the other; (*b*) that the dark matter had not risen into the

upper layer, although (*c*) the latter was full of tubes running in various directions (but seldom straight up) through which the carbonic acid had escaped; (*d*) that the tubes were comparable in size with the dark arborescent markings of Landscape Marble, though on the whole, perhaps, a little larger; and (*e*) that the upper surface of the upper layer was thrown into hills and hollows, with a small hole at the centre of each depression, through which no doubt the last bubbles of carbonic-acid gas had escaped as the material was setting or drying.

(3) A glass tank was made, such as is used for showing chemical reactions on a screen by means of a magic lantern, but made to leak just a little at two opposite corners at the bottom. The lower part was filled with very fine siliceous matter deposited from water, the middle with precipitated calcium carbonate and carbon in the form of lamp-black (both mixed well together before being poured in), and over these some more fine siliceous matter. All being ready, dilute hydrochloric acid was poured into the space above the various sediments, but they now seemed to be impervious, and nothing happened. When I made a connexion between the hydrochloric acid and the dark layer by means of a long needle, the evolution of gas was violent, and there was something like a miniature volcanic eruption. Although not all that I hoped, two additional points of evidence were gained: (*a*) there could be no mistake about the carbon rising with the gas now—in fact, it was carried up so much, and mixed with siliceous material from the sides of the vent, as to form a half-cone, as it were, on each side of the crater; and (*b*) a mixed layer was produced above the siliceous sediment, in which the dark matter (carbon) largely predominated.

I may mention that experiments in test-tubes generally failed, because any slowly generated carbonic acid would lift a plug of even rather coarse wet sand right out of the tube rather than bubble through it. The production of a dome seemed a necessary preliminary to breaking through, and in a test-tube the small superficial area in proportion to thickness of sediment did not admit of dome-formation.

Thus all the main features of the Cotham Stone, with the exception of the differences of mineral character and colour, have been reproduced artificially.

IX. Conditions under which the Landscape Marble was formed.

To sketch imaginative pictures is perhaps more interesting than the investigation of dry facts, but sometimes less profitable; and therefore, although I am about to draw a picture of the conditions under which the Cotham Stone was deposited—as I seem to see it—I do not attach as much importance to this part of the paper as to the preceding pages.

Conceive a broad estuary receiving the drainage and fine sediment of a considerable area of flat fenland, by means of sluggish rivers rising in somewhat higher calcareous lands also covered with

vegetation.[1] Sometimes the water would be chiefly derived from springs within the watershed, and would contain very little sediment, but being highly charged with bicarbonate of lime (as all limestone springs are, particularly if derived from water firstly percolating through decaying vegetable matter) it would deposit some of the carbonate of lime on reaching the shallow and comparatively stagnant water of the estuary, chiefly through loss of carbonic acid consequent on higher temperature.

During a rainfall over the watershed the rivers would receive surface-drainage, in addition to the clear supply from springs. This would contain a considerable quantity of organic matter washed off the surface, and particularly the already much decomposed vegetable matter of bogs and natural ditches.

Thus there would be frequent alternations of nearly pure inorganic matter and mixed sediment, sometimes the inorganic predominating and sometimes the organic; thus too the layers would vary in constitution and thickness, forming the lower striated portion of the stone. At these freshets also, no doubt, the greater part of the argillaceous matter and grains of quartz, etc., would be introduced.

Now and again there would be a heavy rainfall and flooding of the low-lying fenland, and then the streams would not only bring much more sediment and organic matter than usual, so as to produce thicker layers of dark matter, but they would by virtue of their greater velocity and volume tend to re-arrange the material recently deposited in the direction of their course in the estuary, entirely sweeping the bed of all recent sediment along certain lines, and for a certain distance, and re-depositing this matter farther out to sea, or in lenticular masses at its side (16). For, where the rapid water of the river touched the stagnant water of the estuary, strong eddies or miniature whirlpools would be produced, into which would be swept the matter (now more than usually organic) which would otherwise have been spread in a thinner layer over a larger area. These eddies thus would form traps for sediment, and, according to the depth, sedimentation would proceed quietly below, and lenticular masses would be formed (16). Outside the area of the eddies the deposit would go on much as usual, the eddies themselves acting as screens for a time. Where the water was shallow enough the eddies would also disturb the sediment around, and so obliterate all traces of the original stratification, producing a mixed layer not to be distinctly recognized as Cotham Stone (17). Or possibly, in some cases, they would produce depressions which

[1] 'From the frequency of such delicate creatures as insects in the Landscape-stone, and in another band of limestone only a few feet higher, some of which are said to be beautifully preserved, and could not have been long subject to the action of the waves, it is supposed by Mr. Brodie that this part of the Lias may have been formed in an estuary, which received the waters of some neighbouring coasts, and which brought down the remains of insects and plants.'—Herbert Goss, quoted by Dr. H. Woodward in his paper 'On a New Lias Insect,' Geol. Mag. 1892, p. 195.

would afterwards become filled up with other matter in the form of lenticular masses.[1]

After the subsidence of the flood and the resumption of normal conditions, for some time the waters would be more than usually free from organic matter, owing to the washing that the land had previously received, and the sediment would consequently make purer limestone (8).[2]

Let us now consider what is happening in the dark layer whilst this purer limestone is being deposited. The thicker dark layer produced by the supposed flood would consist of vegetable matter less decomposed than that normally brought down, and so under the warm shallow water of the estuary it would continue to decompose, and, like the black ooze from a dirty pond, give off bubbles of gas.

At first the bubbles passed off freely; consequently they were not very large, and having little or no sediment to lift could come off anywhere, and so a great many spurts of dark matter were formed (8). As the calcareous sediment increased in thickness over the organic layer the bubbles of gas escaped less frequently, from a smaller number of points, and were larger; for, before they could free themselves from the sediment, they must have attained sufficient buoyancy to displace the material above them.

The bubbles in rising gave rise to three of the phenomena observed in Landscape Marble:—(*a*) they lifted somewhat the calcareous matter contiguous to their path (8); (*b*) they relieved the pressure behind, so that the dark matter which gave rise to them followed more or less readily according to its plasticity; and (*c*) the white calcareous matter furnished the necessary pressure to cause the dark matter to rise, and as a consequence filled the place from which the latter was driven, thus becoming depressed between the arborescent markings.

As sediment increased and tubes of organic matter were formed in it, these latter themselves became centres for the evolution of gas, and, having less material to lift, would discharge it more often, in deviating paths—mostly, perhaps, in the first instance, through relief of pressure at the side just when a large bubble escaped from a neighbouring vent.

After a considerable time the decomposition of the organic matter would be approaching completion, and three results would follow:—(*a*) the organic matter left would consist chiefly of finely divided carbon; (*b*) the bubbles of gas would be few, large, and far between; and (*c*) when a bubble did escape it would produce vortex rings in the water above, sufficiently powerful to disturb and re-arrange the last layers of calcareous sediment, and well mix it with the black carbon now filling and escaping from the tubes (9). (Layer *F*, figs. 1 & 2.)

Ultimately the escape of gas ceased, and layers similar to those

[1] The specimen shown in fig. 2 (p. 397) appears to have been so situated that it was peculiarly subject to disturbance; both the lower and upper layers appear to have undergone re-arrangement of material.

[2] The matrix in which the arborescent markings occur is much lighter than any other part of the stone.

found at the base of the stone were formed, though even then the production of gas had not entirely ceased, and so the last layers of plastic matter are uplifted in places, thus producing an uneven or mammillated surface. To this result no doubt contraction of the stone on setting contributed, particularly as it had a partly organic and partly gaseous nucleus.

The subsequent changes, which resulted in the formation of aragonite in some cases, and finer crystals of calcite only in others, must be left unexplained for the present. We know that there would be an aqueous solution of carbonic-acid gas under gradually increasing pressure, and in contact with calcium carbonate which it is capable of dissolving.

If the explanation which I have just given of the origin of Landscape Marble be correct, we ought sometimes to find it in other rocks and at other places where like conditions prevailed; and there ought to be grades of development. This really is the case (16, 17). The *Estheria*-bed in the upper part of the Rhætic Beds at Garden Cliff and Westbury-on-Severn, and several others, are mentioned by Mr. H. B. Woodward as instances.[1]

One might be inclined to ask why we do not find these markings in the sands and shales above coal-seams. Well, several circumstances might prevent that. The sedimentation might have been too rapid, so that the bubbles of gas were mostly imprisoned; or the material might have been coarse enough to let the gases pass between the particles without disturbance of the latter. But the chief reason, I suspect, was that the deposition of the shales or sands was not tranquil enough; a very slight movement of the water in contact with sediment would facilitate the escape of gases and obliterate all trace of arborescent markings. It may be, however, that these markings might be found above some coal-seams—if specially looked for.

To the questions—(*a*) Can the arborescent markings occur without the corrugated upper surface? and (*b*) Can the corrugated surface occur without the markings?—I should return in the case of the former a negative, and in the case of the latter an affirmative answer, for although a decomposition of organic matter and evolution of gas sufficient to produce the arborescent markings could scarcely fail to affect the sediment deposited just above, an intimate mixture

[1] When this paper was nearly completed, through the kindness of Mr. H. B. Woodward, I was permitted to see a specimen of limestone from the Purbeck strata of Swanage (Durleston Bay), which in several respects resembles the Cotham Landscape Marble. It is very similar in colour to one of my specimens. It contains peculiar dome-shaped markings, starting from and only above a distinct, sharply-defined, dark layer of the same colour; the upper surface is extremely wrinkled, similar to Landscape Marble, only finer than the specimens of the latter that I have seen, and the bumps seem to correspond with the uppermost domes of darker matter. It differs from Cotham Stone in being of coarser granular structure, of different fracture (not conchoidal); the markings are of a brown colour instead of being almost black, and they reach the surface everywhere, the thickness of the part of the stone in which they occur being less than ½ inch. I certainly think that this Purbeck stone had an origin similar to that of the Cotham Stone, but, as the gases never had any difficulty in escaping, decomposition was more complete—hence greater absence of carbon and more general diffusion of the markings.

of organic and inorganic matter might result in as great an evolution of gas and uplifting of the layers above, although without being able to produce arborescent markings.

Between the top layer of the White Lias—the Sun-bed—and Cotham Stone there are other beds presenting corrugated surfaces in homogeneous limestone. These, I should imagine, contained organic matter, although, on account of its being evenly disseminated in the rock, its previous presence is not noticeable.

Discussion.

Mr. H. B. Woodward remarked that the Landscape Marble occurred at the junction of the black *Avicula contorta*-shales and the White Lias, and exhibited a commingling of dark argillaceous with calcareous sediment. Where the bed was persistent, it was simply banded limestone; where the arborescent markings were present, the bed occurred in nodular and isolated masses, sometimes 4 feet or more across, and with the characteristic crinkly surface. Thus he had concluded that the arborescent markings were produced by irregular changes in the dark and pale muds during the solidification of the stone. In illustration of the connexion between arborescent markings and nodular and crinkly stone, he exhibited specimens from the Purbeck Beds, and also from the *Estheria*-bed (Rhætic) of Westbury-on-Severn. The chemical and physical aspects of the subject he could not discuss, and that had now been ably dealt with by Mr. Thompson.

Prof. T. Rupert Jones drew attention to what he thought was the Rev. Osmond Fisher's suggestion of the cause of the arborescent markings in the Landscape Marble. Among successive layers of mud and tufa, in a marshy district, some of the thicker layers of rotten plants gave way under the superincumbent tufa, which broke down, and the carbonaceous mud was forced up along the lines of breakage. The speaker thought that, by combining this with other hypotheses already alluded to, we might find a true cause of the peculiar markings in the stone.

Mr. F. A. Bather asked whether the drawing represented the specimens the same way up as *in situ*.

Mr. Monckton said there could be no doubt that the mammillated surface was at the top.

The Author said that he first of all desired to thank Mr. H. B. Woodward for his forethought and kindness in exhibiting, by permission of the Director-General of the Geological Survey, various specimens of Landscape Marble and Purbeck Stone showing arborescent and allied markings, in illustration of the paper. In reply to Mr. Woodward's remarks he said that the chief reason for not accepting his explanation of the arborescent markings was that the shrinkage of the stone had not affected the contiguous thinner dark bands; although shrinkage of the upper layers had aided in the formation of the corrugated upper surface. He also replied to several questions, and more fully explained the results obtained in experiments made for the artificial production of the essential and characteristic features of the stone.

26. *The* SYSTEMATIC POSITION *of the* TRILOBITES. By H. M. BERNARD, Esq., M.A., F.L.S., F.Z.S., of the Huxley Research Laboratory, Royal College of Science, London. (Communicated by Dr. HENRY WOODWARD, F.R.S., P.G.S. Read March 7th, 1894.)

IT is now just fifty years since Burmeister[1] wrote that he "was convinced" that the reasons he afforded would be "deemed sufficiently conclusive to satisfy the unprejudiced reader" that "the trilobites were a peculiar family of the crustacea, nearly allied to the existing phyllopoda, approaching the latter family most nearly in its genus *Branchipus*, and forming a link connecting the phyllopoda with the pœcilopoda." Burmeister's reasoning has not, however, been generally considered satisfactory, and his claim that the trilobites are related to the phyllopoda, though recognized as possible,[2] appears somewhat to have waned before the claim put forward by others that they are primitive isopods. But this latter relationship had already been shown by Burmeister to be highly improbable, and this judgment is fully endorsed and further enforced by Gerstaecker, whose monumental review of the crustacea in Bronn's 'Klassen und Ordnungen des Thierreichs' gives special weight to his opinion.[3] In the absence of any certain knowledge as to the character and arrangement of the limbs, Gerstaecker, while recognizing trilobites as crustacea, declines to adopt any special relationship: that is, he is evidently not convinced by Burmeister's reasoning. And it must indeed be admitted that Burmeister's arguments were, in themselves, far from conclusive, even when correct as far as they went. Since the appearance of the 5th volume of Bronn's 'Klassen und Ordnungen' in 1879, however, further facts have come to light which completely justify the conclusions of Burmeister, so far, that is, as to the trilobites having been primitive phyllopods.

My own study of the phyllopod *Apus* brought me, from the purely zoological standpoint and along an entirely different line of reasoning, to very nearly the same conclusion as Burmeister, or, more strictly, to that adopted by Linnæus,[4] who decided in favour of classing the trilobites with *Monoculus Apus*. I endeavoured to show[5] that *Apus* was the ancestral form of all existing crustacea (excluding the ostracoda), and, as such, might be expected to throw light on the trilobites. About the same time as my book was published there appeared a long and very valuable paper on the

[1] 'Die Organisation der Trilobiten aus ihren lebenden Verwandten entwickelt,' Berlin, 1843. See also Engl. transl., edited by T. Bell & Edw. Forbes, Ray Soc. 1846.

[2] Lang's 'Text-book of Comparative Anatomy,' English translation, p. 415.

[3] See further the note at the end on the isopod relationship.

[4] A summary of the different views which have from time to time been put forward as to the systematic position of the trilobites is given by Walcott in his short but invaluable paper: 'The Trilobite: New and Old Evidence relating to its Organization,' Bull. Mus. Comp. Zool. Harvard, vol. viii. (1880–81).

[5] 'The Apodidæ, a Morphological Study,' Nature Series, Macmillan, 1892.

genealogy of the crustacea[1] from the pen of Prof. Carl Grobben, of Vienna, whose well-known researches into the anatomy and embryology of the crustacea lend special weight to his conclusions. Prof. Grobben, after reviewing an immense array of facts and arguments, arrives at the conclusion that all the existing crustacea can be deduced from an *Apus*-like ancestral form.

Since the publication of these conclusions, I have been studying the organization of the trilobites themselves, and I wish here to express my warmest thanks to Dr. Henry Woodward, F.R.S., to Prof. Judd, F.R.S., and to Prof. G. B. Howes, for kindly placing specimens at my disposal for examination, and further to Mr. W. I. Last, Keeper of the Mechanical Department at the South Kensington Museum, for the kindly and invaluable assistance he rendered me in fitting up for me a small sandblast, by means of which I have been endeavouring to 'develop' the fossils.

I. The great variability in the number of the segments shown by the trilobites need hardly be again insisted upon as a feature connecting them with the phyllopods. Of still greater importance is the gradual diminution of the size of the segments posteriorly, which remarkable feature the trilobites share with *Apus*. I have endeavoured to show (*op. jam cit.*) that this feature is explicable by assuming that *Apus* is the 'Protonauplius' of authors, in which a very large number of segments commence to develop, many of which, however, at the posterior end of the body, remain fixed in a rudimentary condition. This explanation of the morphology of *Apus* is, it seems to me, evident if we compare the adult with the developing larva. The adult is but the *grown, not metamorphosed*, larva—grown by the continual development of segments from before backwards, until at a certain stage this process becomes fixed, and we have the adult *Apus* with a number of fixed rudimentary segments.[2] This fixation of a number of undeveloped segments is visible in many trilobites.

In the early *Olenellus* these rudimentary posterior segments are still free (*i. e.* do not form a pygidium). As a rule, however, they form the plate-like pygidium characteristic of the trilobites. This specialization seems to have set in very early; for instance, in *Microdiscus* we find a pygidium apparently consisting of only a few segments differing little in size from those of the trunk, whereas a review of the pygidia of the whole order leaves little doubt that this organ was originally composed of a number of larval segments which diminished gradually in size and development from before backward.

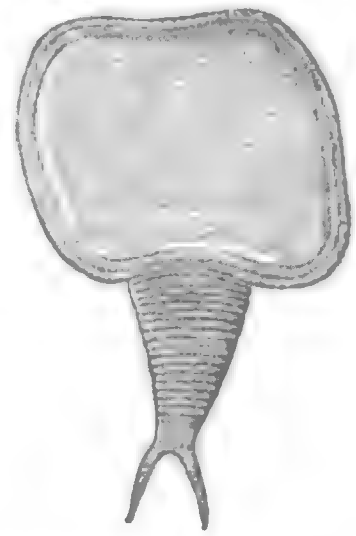
That animals closely resembling *Apus* were extant in earliest

[1] Sitzungsber. d. k. Akad. Wissensch. Wien, vol. ci. (1892) pt. i. pp. 237–274.

[2] In a recent systematic paper on the genus *Apus* (Z. w. Z. 5, pt. 1), Dr. Braem records a remarkable inconstancy in the number of limbless tail-segments within one and the same species. In *A. cancriformis* the number varies from 5 to 8; in *A. numidicus* from 10 to 14; in *A. productus* from 4 to 6; in *A. externus* from 5 to 6. This fact is quite in keeping with the undifferentiated (that is, embryonic) condition of the posterior region of the body.

times we now know for certain, not only from the existence of rich remains of phyllopods with shields closely resembling that of *Apus*,[1] but further from the remarkable Cambrian *Protocaris Marshi*[2] (fig. 1), which apparently possessed the same peculiar character of the posterior segmentation as *Apus*, and which I should like to call *Apus Marshi*.

Fig. 1.—Protocaris Marshi, *Walcott*.



Again, the extinct *Echinocaris* takes its name from a feature which it possessed in common with *Apus*. The posterior cylindrical (and apparently limbless) segments are provided with a ring of spines slightly anterior to the posterior edge of the segment. Serrated posterior edges of these segments occur very generally in the copepoda, and a variation of the arrangement in *Echinocaris* occurs in some stomatopoda, and perhaps on the dorsal sides of other crustacea (not phyllopods). It is, however, very marked in the phyllopods *Apus* and *Estheria*, in the former of which it repeats almost exactly the arrangement in *Echinocaris*, there being a complete ring of sharp spines round each of the posterior segments, slightly in front of its posterior edge. In both *Echinocaris* and *Apus*, further, this special ring of spines is not developed on the anal segment. Moreover, the shell of *Echinocaris* has lateral markings which involuntarily suggest the markings caused by the shell-gland on the carapace of *Apus*. In addition to two caudal cirri, *Echinocaris* had the median prolongation of the anal segment which is characteristic of so many of the Apodidæ (*Lepidurus*).[3]

II. The formation of the head by the gradual incorporation of trunk-segments is now very clearly shown in Walcott's detailed description of the Cambrian trilobites of North America. The composition of the head out of five somites is, as is well known, a crustacean characteristic, although no crustacean now shows this

[1] See 'Monograph of the British Palæozoic Phyllopoda,' pt. i. T. R. Jones and H. Woodward, Palæont. Soc. 1888. See also the paper by Clarke ('American Naturalist,' 1893, p. 793) on the carapace of *Rhinocaris*. It seems to me that the remarkable double suture which he describes for this interesting Devonian crustacean points back to the univalve condition of the original carapace. It is easy to deduce both forms of the carapace, that with a single median, and that with a double suture, from an *Apus*-like shield; whereas it would be difficult to arrange these carapaces in any other order of development.

[2] Walcott, 'On the Cambrian Faunas of North America,' Bull. U.S. Geol. Surv. No. 10, vol. ii. 1884–1885.

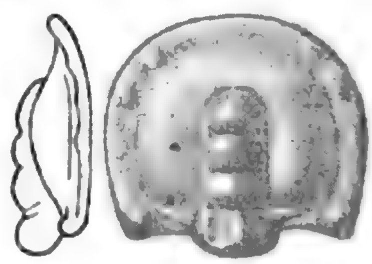
[3] See James Hall's figures, 'Natural History of New York,' pls. xxix.–xxx. vol. vii. (1888).

primitive segmentation of the head-region. It is even quite obscured in *Apus*, and can only be gathered from the number of cephalic appendages.

The head-region of the trilobites is also, as a rule, so specialized that it is no longer possible to make out its exact segmentation. Although five seems to be the usual number of component segments, four forming the glabella, and the fifth the 'occipital ring,' trilobites occur in which all traces of segmentation have disappeared from the glabella, while again, on the other hand, others appear to have six segments forming the head. Barrande has tabulated the apparent segmentation of the heads of the Silurian trilobites of Bohemia (vol. i. pp. 195–7). The numbers range from 2? to 6. There is no reason why the trilobites should not show great variation in the number of the segments composing the head; indeed, the conclusions at which we have arrived concerning their systematic position would lead us to expect such variation. Fortunately, in the ancient Cambrian forms, such as *Microdiscus* and *Olenellus*, the segmentation of the head is so clear that it is almost impossible to misunderstand it. A study of these forms seems indeed to show us the crustacean head in making.

Commencing with *Microdiscus* (fig. 2), we find that it has only four distinct segments embraced by the head-shield. The fourth segment, further, shows traces of quite recent incorporation into the head (see fig. 2, profile). So that this form points back to the time when there were only three segments forming the head-region. There are other trilobites with apparently only four segments in the head (e. g. *Triarthrus Beckii*), which on that account ought, perhaps, to be classed with *Microdiscus* as a group distinct from those with five segments. On the other hand, many trilobites with five head-segments show signs of having arisen from those with only four head-segments, inasmuch as the fifth very often bears the appearance of having been recently incorporated; it frequently retains its strong resemblance to the trunk-segments, and is seldom completely merged with the glabella.

Fig. 2.—*Head-shield of* Microdiscus Meeki, *showing head of four segments, the fourth only partially incorporated in the head.*



[From Walcott, Tenth Report U.S. Geol. Surv. (1890) pl. lxxxi.]

We may, then, safely conclude from the study of adult forms alone: (1) that *Microdiscus* was preceded by a form with three head-segments; (2) that forms with four head-segments, of which examples such as *Microdiscus* have been preserved, preceded the forms with five head-segments; (3) that forms with six head-segments (*Ogygia* and the related *Limulus* and Eurypterids) are to be derived from those with five head-segments.

The formation of the head-region by the fusion and gradual in-

corporation of somites, which is quite obscured in the development of the crustacea, is still perfectly clear in the development of the trilobites, *e. g.* in that of *Olenellus* described and figured by Walcott.[1] This trilobite, with five head-segments in the adult, arose almost certainly from a form with four head-segments; the youngest stage observed has only four segments, with their own characteristic pleuræ, the posterior pairs being bent backward, as terminal pleuræ usually are (fig. 3). When the fifth head-segment appears, it does so as a trunk-segment, *i. e.* with typical trunk-pleuræ; that is, with pleuræ which run out laterally in the transverse plane (see figs. 4 & 5, p. 416). These pleuræ of the fifth head-segment only gradually become incorporated into the head-shield, and in some species their points seem to persist on each side in the middle of the posterior margin of the cephalic shield.

These figures of the developing *Olenellus* are further of special interest because they show without doubt that the segmentation of the head was still very distinct, *i. e.* the fusion of the segments was only of recent occurrence. We find the head-segments diminishing in size from front to back (fig. 4 *a*, p. 416), which is typical of the development of segmented animals when the segments do not belong to a highly specialized region. This early developmental stage no longer appears in the metamorphoses of the crustacea.

Fig. 3.—*Youngest stage of* Olenellus asaphoides ($\frac{1}{5}$ *mm.*) *seen by Walcott.*

[This shows the four head-segments with the anal segment; the cephalic shield apparently consists of the pleuræ of the 1st–4th segments.]

It appears to me, then, that we have, in the trilobites *Microdiscus* and *Olenellus*, two consecutive stages in the development of the crustacean head. But, at the same time, although *Microdiscus*, with its head of four segments, is, in this respect, an older type than *Olenellus*, with its head of five segments, in other respects (for example, in its pygidium) it is more specialized.

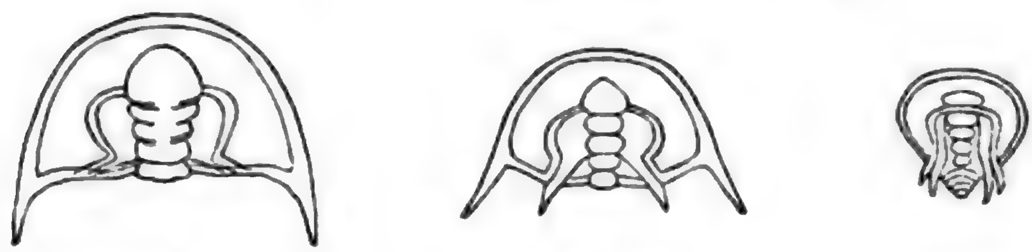
III. The two chief characteristics of the head of these primitive crustacea are (1) the bending round ventrally of the first segment, so that the labrum and mouth face posteriorly; and (2) the cephalic shield.

1. In my endeavour to trace the possible origin of the crustacea from their annelidan ancestor, I laid special stress upon this bending round of the mouth for the purpose of using the parapodia as mouth-organs. I had shown, at first without reference to the trilobites,

[1] 'Fauna of the *Olenellus*-zone' (see especially pl. 4, xxxvi.) in U.S. Geol. Surv. Tenth Report (1890). See also S. W. Ford, 'Embryonic Forms of Trilobites,' Amer. Journ. Sci. ser. 3, vol. xiii. (1877) p. 265, and vol. xxii. (1881) p. 250; some of Walcott's figures are taken from these papers.

and solely from an examination of the external and internal structure of *Apus*, that such bending round must have taken place in the ancestral crustacean ('The Apodidæ,' *op. supra cit.*). But, having only *Apus* as a guide, I had to leave the question undecided as to how many segments actually turned over, *i. e.* into or towards

Fig. 4.—Olenellus asaphoides, *after Ford.*



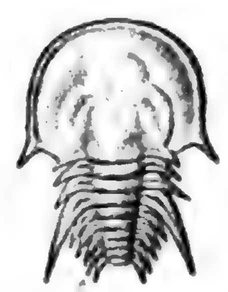
[The order has been accidentally reversed.]

a = Embryonic form: head composed of five segments, which diminish in size from before backward.
b = A further stage of the same.
c = Pleuræ of the fifth segment beginning to take part in the formation of the head-shield.

the horizontal plane. Finding the mandibles (belonging to the third segment) arranged dorso-ventrally, I have since been inclined to think that the third segment remained more or less completely in the transverse plane. I should therefore have assigned the chief part in the formation of the bend to the first and second segments.

A study of *Olenellus*, in which the segmentation of the head is especially distinct, shows us that such a bending round did actually take place, but that it was primarily confined to one, *i. e.* to the first, segment. By the bending round of the first segment, so that the labrum and mouth point backward, thus apparent in the trilobites, we can, as I have shown, obtain an explanation of the pre-oral position of the antennæ in the crustacea, and, further, of the bend in the alimentary canal also characteristic of the group, and especially marked in *Apus* and *Limulus*. In this latter animal, indeed, the backward bend of the œsophagus has been secondarily exaggerated. The same may also have taken place in *Apus*. If so, it must be attributed to the gradual backward growth of the mouth, so as to allow a greater number of limbs to function as mouth-parts. In *Limulus* the basal plates of five pairs of limbs

Fig. 5.—*Young specimen of* Olenellus asaphoides.



[The pleuræ of the fifth head-segment are seen to resemble those of the trunk-segments.]

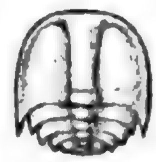
function as jaws, a specialization further developed in the Eurypteridæ, in which the most posterior of these becomes the most powerful.

The great development of the glabella in many trilobites may perhaps be due in some cases to the great development of the œsophagus as a 'masticatory stomach,' or, again, of the mid-gut diverticula ('liver'), which almost certainly occupied this part of the body (cf. *Limulus* and *Apus*).

My theoretical deduction of all crustacea from an annelid in which the anterior end was bent round ventrally, so as to allow of its appendages to function as jaws, is thus fully confirmed by these early trilobites.

2. The head-shield seems to have been a characteristic of all the earliest crustacea. I endeavoured (in 'The Apodidæ') to explain it as starting from the lateral projections which would be necessarily caused by the sharp bending round of the first segment. A careful study of the series of under-surfaces of the heads (especially of *Dalmanites socialis* and *Paradoxides bohemicus*) figured by Barrande[1] has confirmed me in this supposition.

Fig. 6.—Sao hirsuta, *after Barrande.*



[Early stage, showing lateral projections as due to bending of first segment.]

Still more conclusive evidence, however, on this point is yielded by the developmental history of *Sao hirsuta*, also given in Barrande's classical work. Stages 1–8 show the first segment produced on each side into points curving backwards round the outer edges of the cephalic shield (see fig. 6). In stage 9 this is nearly obscured, while the head-shield of the adult is very highly specialized and shows no traces of its origin.

The head-shield thus almost certainly originated in the first segment, as a pair of lateral projections due to the sharp bend in that segment. The backward growth of these projections, *i. e.* their repetition on the following segments as pleuræ, was a natural process.

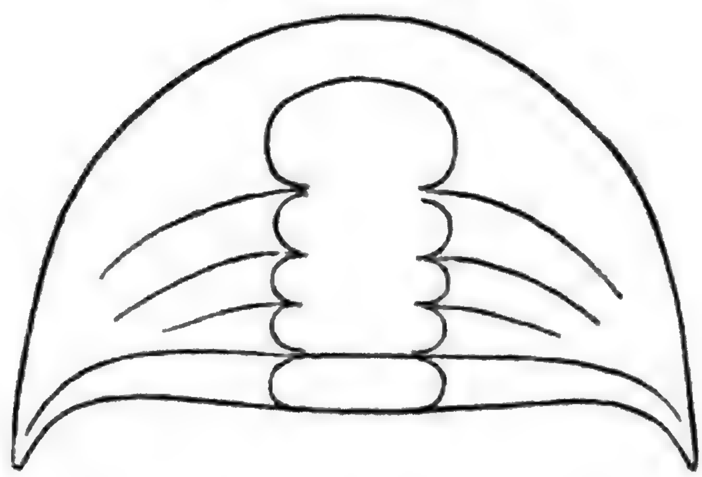
In *Microdiscus* the head-shield extends backward through three segments, the fourth segment being not yet quite incorporated into it. When five segments became definitely fixed as the normal number of head-segments, the head-shield ran back to the posterior edge of the fifth segment. Not only, however, does this fifth segment often appear like a trunk-somite, but the transverse strip of the head-shield belonging to it very often appears, as above noted, to be a pair of pleuræ belonging to the trunk-segments, fused along their anterior edges with the cephalic shield.

This fact, namely, that the comparatively recent incorporation of the pleuræ of the fifth head-segment is still visible, helps us to understand the morphology of the head-shield. As above suggested, we

[1] 'Système silurien de la Bohême,' vol. i. (1852) Trilobites, pls. 2 A and 2 B.

may safely describe it as consisting of the fused lateral projections of the cephalic segments. The first pair, I think, were the lateral projections which would naturally be formed by the bending round of the first segment. This first pair of projections would give rise to a second pair belonging to the second segment. I say 'would give rise' because, from the method of development of segmented animals, the metameric repetition of special structures is a well-known fact. We can thus suppose three pairs of 'pleuræ,' diminishing in size, developed on the 2nd, 3rd, and 4th segments

Fig. 7.—*Diagram showing the probable composition of the head-shield.*



as metameric repetitions of the lateral projections of the first segment. This stage seems indeed to be represented in the larval *Olenellus* (fig. 3, p. 415), in which we have the head-shield composed of the secondarily enlarged lateral projections of the first segment, and three pairs of pleuræ. These posterior pleuræ of the posterior developing head-segments slope directly backward, just as do the pleuræ of the posterior tail-segments, which are also rudimentary. I consider this latter point of great morphological importance, as it seems to show that the head-shield was a structure *sui generis*.

This head-shield, composed of the pleuræ of four segments, in the same way gave rise in the trilobites to large pleuræ on the subsequently developed trunk-segments, these pleuræ generally diminishing in size from front to back. If the first pair of these pleuræ fuse with the head-shield, as above described, we should get a head-shield composed of (1) the lateral projections of the first segment, (2) the pleuræ of the second, (3) the smaller pleuræ of the third segment, (4) the still smaller pleuræ of the fourth segment, (5) the pair of the large pleuræ of the most recently incorporated trunk-segment forming the fifth cephalic segment. This origin is further illustrated by the diagram (fig. 7). That diagram finds ample justification in the series of figures 3, 4, 5, and 6, in which we trace the rise of the fifth cephalic segment, with the gradual development and incorporation into the head-shield of its pleuræ, which are typical trunk-pleuræ.

It is further of especial interest to note that the lines of fusion between the lateral projections of the first segment and the pleuræ of the second segment apparently correspond with the posterior halves of the mysterious cephalic sutures. Many trilobites have these sutures running out laterally, as if dividing the shield into two somewhat similar pleuræ (e.g. *Cromus intercostatus* and *Dalmanites*).[1] The symmetry of the line itself has, however, been broken by the wandering backwards of the eye-tubercle, which, as we shall see, belonged originally to the first segment, and wandered only secondarily on to its lateral projections. The larval forms of *Olenellus* (fig. 3, p. 415) show how this line might run almost straight backwards when the first pair of projections are very largely developed in comparison with the pleuræ of the following segments, which, like the pleuræ of the rudimentary tail-segments, may slope backwards.

The retention of the line of fusion[2] between the anterior edges of the pleuræ of the second head-segment with the lateral projections of the first segment, as a line of weakness through the thick dorsal head-shield, may have been useful for ecdysis. The thin ventral membrane would no doubt have split easily; but, for the drawing out of the limbs, etc., it is necessary to open up the dorsal surface. This would have been extremely difficult in the case of the trilobites, unless special provision had been made for it. Both *Limulus* and *Apus* are said to moult by splitting along the frontal edge. In the trilobites, the splitting generally appears to have left the frontal edge on each side of the glabella and to have run back to the eyes; it then followed the line along the inner posterior edges of the eyes, which, as above stated, may well have been the original line of fusion of the first and second pairs of pleuræ forming the head-shield.

IV. In endeavouring to deduce *Apus* from a carnivorous annelid, by the bending round of the first segment, I had assumed that the eyes were originally on the prostomium (as they are typically in carnivorous annelids), and that when this was bent round ventrally they wandered up on to the dorsal surface of the first segment. Clear traces of this wandering of the eyes from the ventral on to the dorsal surface can still be found in the development of *Apus*, the eyes showing a gradual dorsal displacement during development. I brought forward also some morphological evidence in favour of this dorsal wandering of the eyes of *Apus*; for instance, the position and shape of the brain and antennal nerves seem best explained on the assumption that the brain had been dragged out of its original

[1] An almost similar suggestion was made by M'Coy, 'On the Classification of some British Fossil Crustacea,' Ann. & Mag. Nat. Hist. ser. 2. vol. iv. 1849, who concluded, from the position of the eyes as belonging to the first 'ring,' that the suture running posterior to them was the line of junction of the first and second rings. He claimed the whole sutures as such. I would, however, only claim the posterior portions of the suture, believing that the anterior lobe of the glabella certainly belongs to the first segment.

[2] S. W. Ford, Am. Journ. Sci. ser. 3. vol. xiii. (1877) p. 267, if I understand him aright, states that this fusion is incomplete in the youngest stages.

[illegible]

(a) The claw, in most trilobites, was found at varying distances from the glabella, [illegible]

(b) [illegible]

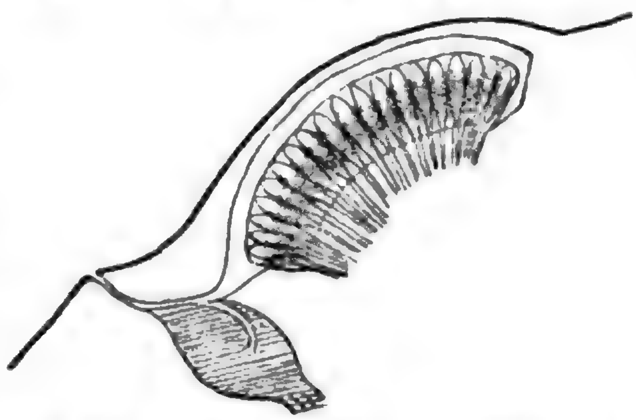
(c) Many of the early trilobites, e.g. *Paradoxides*, [illegible]

[illegible]

furrow between the glabella and cheek in trilobites which appear to be eyeless, may be the same structures, only closer to the eyes. Perhaps too the curious marks on each side of the glabella in *Phacops Volborthii* and *Ph. fecundus* may also come under the same head: that is, they may all be openings, or the remains of openings, into water-sacs over the eyes.

(*d*) According to this interpretation of the facts, water-sacs must have originally been present over the eyes of all these primitive crustacea, completely degenerating, however, in later forms. The trilobites afford some interesting, though indirect and not conclusive, evidence on this point. As is well known, in the earliest trilobites the 'eye-membrane' is generally wanting. Gerstaecker[1] would account for this as due to the enormous pressure to which the Lower Silurian fossils were exposed. I would suggest, as a more probable interpretation, that the eye proper was not in actual contact with the outer cuticle, but lying in a pocket which would fall away from the outer cuticle as the animal tissues decayed. In *Apus*, the eye, not being attached to the outer cuticle, but belonging to the thin cuticle of the water-sac (see fig. 8), easily falls away from the former in the process of section-cutting; only as the water-sacs degenerated (as they have done in the higher crustacea), and as the eyes became secondarily attached to the external cuticle, would they be preserved.

Fig. 8.—*Diagram of the eye of* Apus.



[The eye is sunk beneath the surface in a water-sac, and is therefore not in contact with the outer cuticle.]

We may, then, suppose that in the earlier trilobites the external cuticle was differentiated, above where the eyes were situated in the water-sacs, so as to form a kind of thin and membranous cornea, which would be easily destroyed. This would explain the frequent collapse of the 'eye-membrane.' Again, in other trilobites, the external cuticle above the eyes may have shown no such differentiation into a smooth membranous cornea, the eyes lying in the water-sacs under a generally transparent cuticle. These trilobites would now appear to have been blind, whereas their eyes were more probably in pockets under the external cuticle. *Microdiscus* has no eyes visible. It is interesting to note M'Coy's observation (quoted by Dr. Woodward, *op. supra cit.*) that the pores above mentioned are most obvious in 'blind' trilobites.

(*e*) The eyes which do appear in trilobites show very marked differences, which Burmeister, with great ingenuity, endeavoured to

[1] Bronn's 'Klassen und Ordnungen,' vol. v. p. 1168.

show might be due to the presence or absence (presumably through post-mortem destruction) of a thin membranous cornea, which he assumes covered the eyes of the trilobites, similar to that which covers the eye in *Branchipus*. I have always considered this membranous cornea of *Branchipus* as indicatory of the former presence of a water-sac, which secondarily disappeared as the eye became stalked; otherwise it seemed difficult to explain why the eye itself did not belong to the external cuticle represented by the cornea. In the same way, among some of the later trilobites, the water-sac probably degenerated secondarily, leaving the eye in contact with, but not strictly belonging to, the outer cuticle, which may have covered the eye like a thin membrane. This whole subject is, however, beset with great difficulties, so that it is impossible as yet to come to any definite conclusion; for while, on the one hand, the so-called faceted eyes of trilobites, showing round projecting single eyes arranged at some distance from one another, remind one strongly of the tips of crystalline cones,[1] such as occur in the eyes of *Apus* (see fig. 8, p. 421), on the other it is clear from Clarke's[2] researches that these were certainly in some cases true corneal lenses, apparently belonging to the outer cuticle, and, indeed, somewhat elaborate structures.

Further, the eye of *Limulus* is a great difficulty; here we have no trace of a water-sac, nor of corneal lenses, while the bodies which appear analogous to the crystalline cones are simply inward projections of the outer cuticle. In discussing the eye of *Apus*, I was led to the conclusion that the eye of *Limulus* was the more primitive, a conclusion also arrived at by Watase.[3] If this is so, then these eyes certainly belong to the external cuticle primarily, and not secondarily by the degeneration of a water-sac. The only way out of the difficulty, it seems to me, is to assume that while, in some cases, the eyes, in travelling backwards, passed beneath a fold of the cuticle into deep pockets, as above described, in others the folds themselves degenerated secondarily, leaving the eyes once more on the free exterior surface of the head.

V. Behind the eyes of *Apus* there occurs, in all species of the Apodidæ that I have examined, the well-known 'dorsal organ,' which in *Apus* appears to be an excretory organ.[4] It is often raised on a slight plateau above the surrounding cuticle; the cuticle of the plateau itself is extremely thin, and likely to collapse easily during the early stages of fossilization. Did such an organ occur on the dorsal surface of the head of the trilobites? Fig. 9 (p. 423) shows us that, in the Cambrian trilobite *Olenellus asaphoides*, there was such an organ, of essentially the same shape as that in *Apus*, but apparently shifted farther back than in *Apus*, that is, on to the fifth segment. In

[1] See Packard, 'The Structure of the Eye of the Trilobites,' in the 'American Naturalist' for 1880.

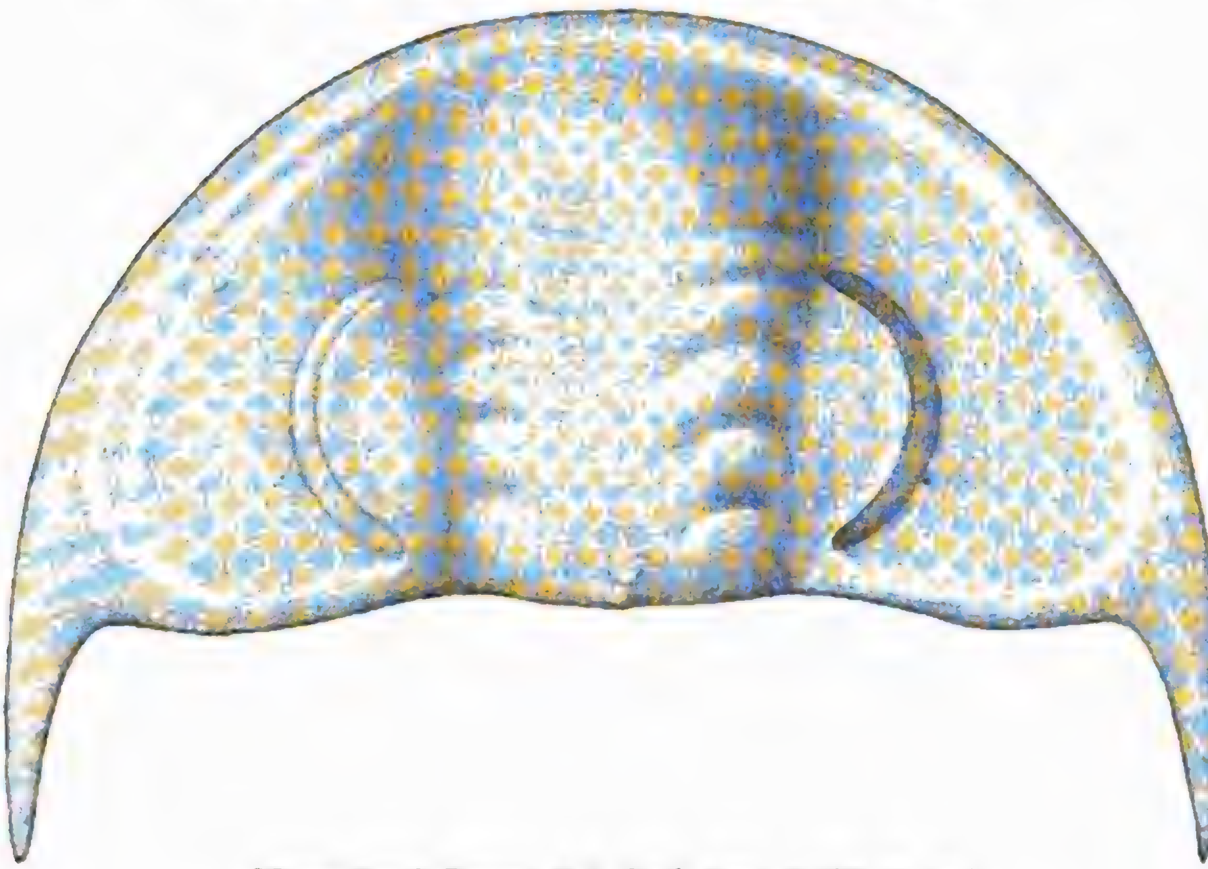
[2] 'Structure and Development of the Visual Area in the Trilobite *Phacops Rana*, Green,' Journ. Morph. vol. ii. (1889).

[3] 'Morphology of the Compound Eyes of Arthropods,' Journ. Roy. Micr. Soc. 1890, p. 318.

[4] 'The Apodidæ,' p. 304.

Apus its exact position with reference to the segmentation is difficult to ascertain. As some evidence of this wandering backwards of the organ in the trilobites, I would draw attention to the sloping backwards of the lines of constriction between the posterior head-segments shown in fig. 9; and further to the fact that Walcott describes a tubercle on the fourth (last) head-segment of *Microdiscus*, whereas, where five segments form the head, it is generally found on the fifth. *Asaphus* seems to form an exception, for the tubercle (?) appears to occur on the fourth segment, and not on the fifth.

Fig. 9.—*Head-shield of* Olenellus (Mesonacis) asaphoides, *showing the oval 'dorsal organ' on the fifth cephalic segment.*



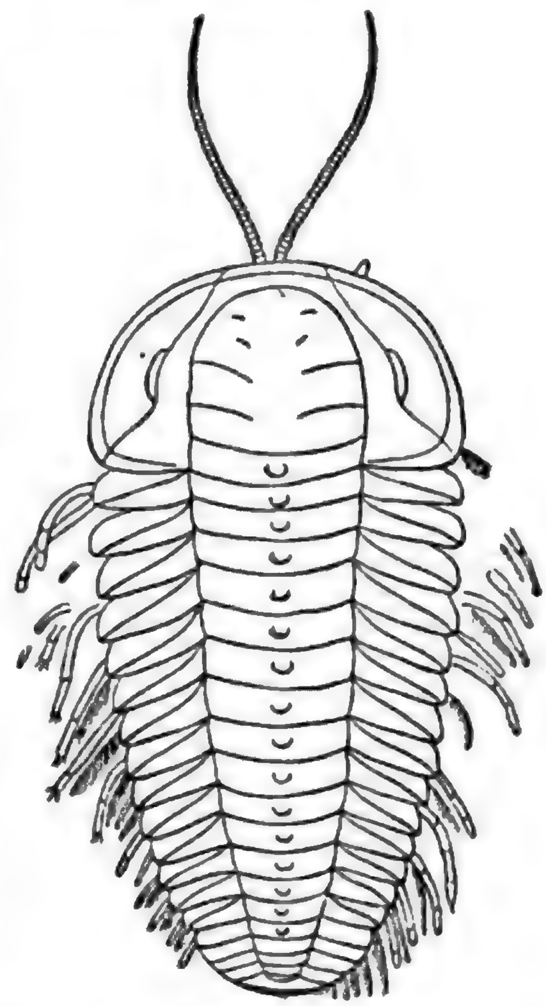
[From Tenth Report U.S. Geol. Surv. (1890) pl. xc.]

This organ seems, in the trilobites as in the crustacea, to have been very early modified. It develops in the former into a slightly conical prominence in *Isotelus*, or into a long sharp spine, *e. g.* in *Olenellus Bröggeri*. Traces of it appear in very many Cambrian and Silurian trilobites, for example, in species of *Dalmanites*, *Asaphus* (on the fourth segment), *Cheirurus*, *Bronteus*, *Proetus*, *Cyphaspis*, *Acidaspis* (either as a median spine or as a circumvallate pit between two lateral spines), *Conocephalites*, *Hydrocephalus*. In the Carboniferous trilobites figured in Dr. Woodward's monograph,[1] traces of it are marked in species of *Phillipsia* and *Griffithides*. In many of these it occurs as a round mark, the exact nature of which is difficult to ascertain. In *Olenellus Bröggeri* and in some species of *Sao* and *Acidaspis*, as above stated, it is produced into a sharp median spine. That all these structures are modifications of the oval patch on the

[1] Palæont. Soc. vols. xxxvii. & xxxviii.

(fig. 11). These antennæ, as far as can be ascertained, were attached on each side of the labrum,[1] and may be assumed to have belonged to the first segment, that is, they were homologous with the first antennæ of *Apus*. These very pronounced antennæ were evidently specialized in this particular trilobite; but we may naturally infer from them that all trilobites had appendages on the first segment which were, as a rule, sensory organs. The exact form which they assumed is a matter of little morphological importance. In some they may have developed pincers (cf. *Limulus* and *Pterygotus*[2]), but in the majority of cases they more probably remained purely sensory.

Fig. 11.—*Specimen of* Triarthrus Beckii, *showing the antennæ.* (*After Beecher.*)



As to the appendages of the following head-segments, we should probably find every grade of specialization, from the lowest trilobites upward. The simplest would be that stage in which the head-appendages did not differ either one from the other or from those of the trunk: all alike being, in all probability, membranous lobes deducible from the parapodia of their annelidan ancestors. The ventral portions of these were, in all probability, masticatory ridges, and preeminently specialized as such in the region of the mouth. Dr. Woodward's discovery of one of these head-appendages in *Asaphus platycephalus*[3] shows the basal masticatory ridge, while the dorsal portion is developed into a jointed cirrus-like process (cf. *Pterygotus*). In some trilobites all the four pairs of posterior cephalic appendages may have presented this character, the masticatory plates being about equally developed (as in *Limulus*), whereas the dorsal portions were either sensory organs or walking-limbs. *The great interest which attaches*

[1] [While this paper was passing through the press, a paper appeared by Walcott, 'Note on some Appendages of the Trilobites,' Geol. Mag. June 1894, p. 246, which contains a figure of a *Triarthrus*, showing the attachment of these antennæ in exactly the position which the first antennæ occupy in *Apus*. As to the great importance of this, see my note in 'Nature,' vol. xlviii. (1893) p. 582.—H. M. B., June, 1894.]

[2] And, according to Laurie, *Slimonia*, 'The Anatomy and Relations of the Eurypteridæ.' Trans. Roy. Soc. Edin. vol. xxxvii. pt. ii. (1893) p. 509.

[3] Quart. Journ. Geol. Soc. vol. xxvi. (1870) p. 486.

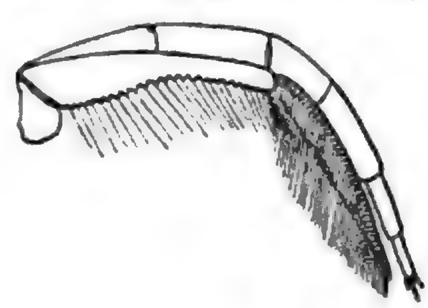
to Apus *lies in the fact that in this form we have the specialization of the mouth-parts which remained typical of the later crustacea.* In *Apus* the second antennæ degenerated, that is, as compared with the anterior pair, their ventral masticatory portions almost, if not entirely, disappearing. In the third pair of limbs it is the dorsal portion which entirely disappears, while the ventral develops into a large fleshy jaw. In the last two limbs the dorsal portions persist in a rudimentary condition, while the ventral are masticatory ridges, second in importance only to the 'mandibles.' On the trunk the masticatory portion of the limbs progressively gives up its function, while the dorsal portions develop primarily as organs of locomotion.

There is no reason to believe that any trilobites possessed this formula for the cephalic appendages. Certainly in the older trilobites, in which we find the head-region either incomplete as to the number of the segments, or with the typical number of segments but not very closely fused together, it was not likely that the limbs of these segments were specialized like those of *Apus* and the higher crustacea, in which the head-segments are fused beyond all further recognition as such. Judging, indeed, from those merostomata whose cephalic limbs we know anything about, there is reason to believe that the trilobites tried almost every possible masticatory formula.

As to the limbs of the trunk, Burmeister assumed that they were membranous 'lobes' like those of *Apus* and *Branchipus*. Recent discoveries, however, show that the ambulatory portion of the leg was filiform; yet Burmeister was not far from the truth. The limb of the trilobite, according to Walcott's sections, was a biramose appendage, with a gill, a cirrus (exopodite), and a locomotory 'endopodite,' and, what is of equal, if not of greater importance, a flat, membranous, basal portion.

Commencing with the distal portion of the leg, Walcott's claim that it was biramose has now been fully confirmed by the discovery of specimens of *Triarthrus Beckii* showing appendages.[1] In these beautiful specimens we have the distal portions of the limbs shown us closely resembling those of *Apus*, only in *Apus* the two branches are flat and membranous for swimming, while in *Triarthrus* they are apparently longer and narrower and secondarily jointed, for crawling. As all who have examined *Apus* know, the two branches are arranged side by side exactly as we find in *Triarthrus* (fig. 12), the exopodite being behind the endopodite.

Fig. 12.—*Limb of* Triarthrus Beckii. (*After Beecher.*)



[1] See Walcott's valuable paper quoted above, and also the more recent paper by Matthew, and further Dr. C. E. Beecher, 'On the Thoracic Legs of *Triarthrus*,' Amer. Journ. Sci. ser. 3, vol. xlvi. (1893) p. 467.

It is only when the limb is flattened out under a cover-glass that the exopodite assumes its true morphological position as a dorsal appendage of the endopodite, branching off laterally in the transverse plane. Further, the flat rowing exopodite of *Apus* is supplied with a fringe of sensory hairs. These hairs are very marked on the exopodite of *Triarthrus*, which, as above noted, has the same position with reference to the endopodite as in *Apus*.

Proximally to these two branches, *Apus* has a gill on the dorsal side of the limb. This organ is either not uncovered in any of the described specimens of *Triarthrus*, or else was quite rudimentary in these animals. But Walcott's researches have led him to the conclusion that the trilobites possessed gills in the typical place, and often, in adaptation no doubt to their manner of life, highly specialized structures.

Fig. 13.—*Section of* Calymene senaria. (*After Walcott.*)

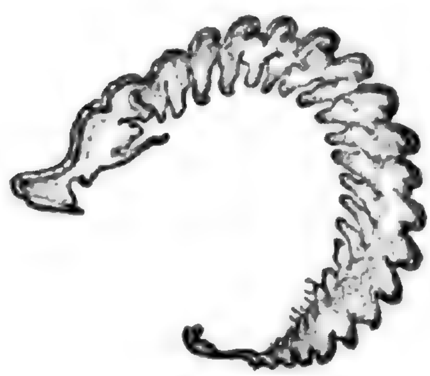
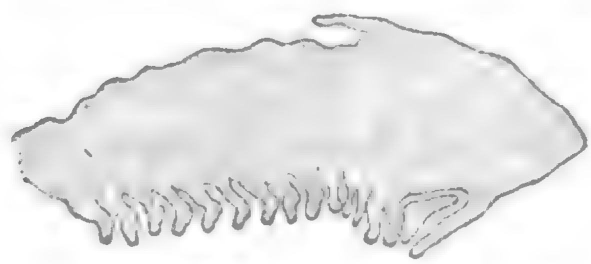


Fig. 14.—*Corresponding section through* Apus (Lepidurus) spitzbergensis, *Bernard.*



So far, then, we have the limbs of the trilobites fundamentally of the same type as those of *Apus*. But the question of prime importance still remains to be answered—were the trilobite-legs phyllopodan, or, considering their more filamentous distal portions, do they show any traces of having been originally membranous appendages with broad transverse insertions?

Walcott's figures appear to me to leave no doubt on this point. The sections (figs. 13 & 15, from Walcott) are almost exactly paralleled by longitudinal sections of *Apus* (figs. 14 & 16), so far, that is, as the section through the limbs is concerned. The limb of *Apus* has a long transverse attachment, partly to the ventral and partly to the lateral surface of the body. Sagittal sections cut laterally (fig. 16, p. 428) show the divisions between the limbs running high up the sides of the body as in the corresponding section of *Calymene senaria* (fig. 15, p. 428). Fig. 13 shows a section through the same trilobite, and fig. 14 one through *Apus*, passing through the lobate basal portion of the limbs farther in, that is, nearer to the median plane. On comparing the four sections here given, we thus have, in both animals, the attachments of the limbs occurring not only in tangential sections, but in those taken much farther in towards the median line. This can have but one explanation, namely,

that the limbs in *Calymene*, as in *Apus*, had long transverse lines of attachment. Further, the shape of the limbs of *Apus* in section is almost exactly the same as the sections of the limbs shown in *Calymene senaria*. This comparison with the section of *Apus* makes it very clear that the section (fig. 13) passed through the membranous basal portions of the limbs of *Calymene*, and does not contain longitudinal sections of the legs themselves, showing traces of joints, as Walcott very naturally, but I think erroneously, infers.

Fig. 15.—*A more tangential longitudinal section of* Calymene senaria. (*After Walcott.*)

Fig. 16.—*Corresponding section of* Apus (Lepidurus) spitzbergensis, *Bernard.*

That the limbs in the trilobites had long transverse insertions, as in *Apus*, seems to me also to be established by fig. 17 (from Walcott), which represents a rolled-up *Calymene senaria* with a portion of the dorsal test broken out, showing a cast of the ventral surface. From this we see that the limbs were certainly, at their origin at least, membranous lobes which sloped forward, as shown in fig. 13 (p. 427). Walcott himself does not seem to have allowed for this forward slope, in concluding from his sections that the membranous lobe had but comparatively a short transverse attachment, the limb afterwards swelling out transversely into a flat triangular basal piece. If the plane of transverse section passed through the apex of one of the bent[1] black lines representing the lines of insertion of the limbs in fig. 17, we should get exactly the appearance adopted by Walcott in his ideal restored section, *i. e.* a broad basal joint with narrow attachment. Further, Walcott's own sections show in other places that the line of insertion was in reality not so short.

Fig. 17.—*Enrolled* Calymene. (*After Walcott.*)

[The dorsal test is broken, showing a cast of the inner ventral surface.]

Judging, then, from these valuable sections compared with trans-

[1] I cannot be quite sure whether I am interpreting the figure correctly; part of the lighter lines may be meant to represent dorsal muscular apophyses. This, however, would not affect the main argument.

verse and longitudinal sections of *Apus*, I am convinced that the basal regions of the limbs of trilobites were membranous lobes with long transverse insertions, which probably passed laterally into the membranous under-surfaces of the pleuræ. Fig. 15 is, I think, completely explained by this supposition.

These membranous basal plates probably projected inwards towards the ventral median line all along the trunk, as they still do in *Apus*, perhaps as segmental repetitions of the masticatory plates round the mouth. In *Apus*, I believe, they are still functional, and serve to push food forward towards the head and mouth. The anterior pairs are armed with teeth, and foreshadow the maxillipedes of the higher malacostraca.

We conclude, then, that the limbs of the trilobites, in spite of their development of filiform ambulatory legs, were originally membranous lobes, and that their basal regions persisted as such. This is of primary importance, as it places their affinity with the phyllopods beyond question.[1]

Of equal importance is the fact which I have elsewhere already insisted upon, that the limbs of the trilobites show the same gradual diminution in size from front to back which we find in *Apus*, the most posterior being quite minute and rudimentary. If my explanation of this remarkable phenomenon be correct, namely: that these posterior segments are fixed in an undeveloped larval condition, then these early phyllopods were clearly not very far removed from ancestors with a very much richer segmentation than they themselves possess, or than *Apus* possesses. *Apus cancriformis* develops, or commences to develop, upwards of sixty segments, and may thus well be descended from a form with seventy to eighty, or even a hundred segments.

Summary.

It is now possible, from the foregoing considerations, to fix with great probability the zoological position of the trilobites. The bending round ventrally of the first segment, the great labrum with antennæ attached at its sides, the 'wandering' of the eyes, the pores (pointing to the probable presence of water-sacs), the head with a varying and progressively increasing number of segments, the dorsal organ, the rudimentary character of the posterior segments, and the gradual diminution in size, with the essentially lobate or phyllopodan type, of the limbs, all serve to connect the trilobites with *Apus*.

This relationship cannot, however, be considered as direct. *Apus*, on account of its richer segmentation, the absence of pleuræ on the

[1] [Since this paper was read, Dr. Beecher has described the 'Appendages of the Pygidium of *Triarthrus*,' Amer. Journ. Sci. ser. 3, vol. xlvii. p. 298, April, 1894. *The limbs of the rudimentary pygidial segments of* Triarthrus *are almost indistinguishable from the rudimentary limbs of the larval segments in a growing* Apus, *which till now were unique among the limbs of arthropods.* The limbs of trilobites, whatever their adult form, were therefore beyond question developments of originally phyllopodan appendages. Their transitions from front to back, that is, from filamentous to membranous, is also exactly paralleled in *Apus*, see figs. 9, 4, 5, and 10 in 'The Apodidæ.'—H. M. B., June, 1894.]

trunk-segments, and its more membranous parapodia-like limbs, must be assumed to lie in the direct line upwards from the original annelidan ancestor towards the modern crustacea. The trilobites then must have branched off laterally from this line either once or more than once, in times anterior to the primitive *Apus*, as forms specialized for creeping under the protection of a hard imbricated carapace. This carapace was obtained by the repetition, on the trunk-segments, of the head-shield which, as we have already seen, almost certainly existed as a structure *sui generis* in earlier forms, and, somewhat modified, has been retained as such in the early crustacea proper ('Aspidophora').

Reading downwards, we should arrange the relationship as follows:—

A richly segmented annelidan ancestor, with the first segment bent round, so that the labrum and mouth point backwards, in order that the parapodia may function as mouth-parts; projections due to this bending round occur at the sides of the first, or flexed, segment.

The second segment fuses with the first to form a head of two segments. The lateral projections, secondarily specialized, are repeated on the second segment as pleuræ, which fuse with the lateral projections of the first segment.

Three segments form the head-region, and two pairs of pleuræ fuse with the lateral projections to form a head-shield.

Four segments form the head-region, and their lateral projections form the head-shield. This head-shield *is not* repeated as pleuræ along the trunk-segments.	*Microdiscus* and other trilobites which have only four segments in the head, and in which the head-shield *is* repeated as pleuræ along the trunk-segments.
Five segments form the head-region, their pleuræ forming the head-shield, which *is not* repeated as pleuræ along the trunk-segments.	*Olenellus* and other trilobites with five head-segments. These may either be deduced from trilobites with four head-segments, or have branched off independently from the main stem. The pleuræ are repeated along the trunk-segments for a creeping manner of life. With various formulæ of the cephalic limbs.
Head-shield developing backwards as a carapace. *Apus*.	Trilobites (e. g. *Ogygia*) with six segments forming the cephalic region, due probably to the association of the powerful limbs[1] of the sixth segment with the mouth-parts.
Modern crustacea.	*Limulus*. Eurypterids (with secondary degeneration of the pleuræ).

[1] Compare the special development of the first trunk-limbs of *Apus*, and of *Calymene* according to Walcott's restoration.

In this provisional classification we have assumed that *Microdiscus* and *Olenellus* branched off, perhaps independently, from the main stem, as forms specialized for creeping—by the development of the pleuræ along the whole length of the body. It is obvious, of course, that there is an alternative scheme, namely, that which assumes that *Microdiscus* and *Olenellus* stand more or less in the direct line, and that *Apus* branched off from *Olenellus* (each having five head-segments). *Apus* in this case would be a later specialization, characterized by a failure to develop the pleuræ (for example, the Eurypterids) along the trunk-segments, perhaps in adaptation to a more free-swimming manner of life. In that case, its cylindrical vermiform body would be a return to ancestral conditions.

The classification would then be as follows:—

Browsing annelid, with first segment bent round, and lateral projections.

↓

With two segments fused to form the head, the lateral projections being repeated all along the body as pleuræ.

↓

With head of three segments, etc. The same.

↓

With head of four segments, e. g. *Microdiscus* and others.

↓

With head of five segments, e. g. *Olenellus* and other trilobites with five head-segments.

↓

Trilobites with six cephalic segments. — *Apus*, in which the pleuræ are secondarily limited to the head-segments, forming the head-shield, which by backward prolongation becomes the carapace.

↓

Eurypterids (also with secondary degeneration of the pleuræ). — *Limulus*.

For my own part, I find the former classification the more acceptable. The repetition of the head-shield as pleuræ along the trunk-segments, seems to be the *specialization* which characterizes the trilobites. If *Apus* cannot show the primitive segmentation of the head, no trilobite can show the vermiform body and the rich segmentation of *Apus*.

It seems to me, therefore, that the trilobites, studied in the light of new discoveries, especially of those which we owe to American investigators, yield the most interesting and important evidence as to the origin of the crustacea. Stripped of their pleuræ and of the expansion of the head-shield, we have, in the early trilobites (e. g. *Olenellus*), long segmented animals tapering at the posterior end. The first segment is bent round ventrally, so that the large labrum points backwards. The appendages of the first segment appear to have functioned as sensory organs and to have pointed downwards, being inserted at the sides of the labrum. The following segments were provided with membranous lobate appendages carrying, on their

dorsal edges, gills and sensory cirri, and distally specialized into locomotory organs. The alimentary canal ran through the whole length of the body, bending round anteriorly to open through the mouth.

The trilobites may thus be briefly described *as fixed specialized stages in the evolution of the crustacea from an annelidan ancestor, which bent its mouth round ventrally so as to use its parapodia as jaws.*

Postscript on the Relation of the Isopods to the Trilobites.

[The suggestion that the isopods are the modern representatives of the trilobites must be judged on its own merits. The argument in the foregoing paper is not in any way affected by it. The relationship between *Apus* and the trilobites would remain intact, the question being merely the following, "Can the isopods be deduced directly from trilobites with five head-segments, that is, can they be drawn from the main crustacean stem below *Apus*, or have they branched off from the higher crustacea above *Apus*?" The former is practically the position taken up by MacLeay[1] (referred to by the President in the discussion which followed the reading of the above paper). That able observer recognized the relationship between *Apus* and the trilobites, but placed the latter between *Apus* and the amphipods, probably without any clear notion of what we now mean by descent.

I am myself disposed to think that the isopods and amphipods are but repetitions of the same process above *Apus* as that which is illustrated by the trilobites below *Apus*. If the trilobites were primitive crustacea lower than *Apus*, specially adapted to a creeping mode of life, the isopods may be crustaceans higher than *Apus* adapted to the same mode of life, and therefore closely resembling the trilobites. The well-developed anteriorly-placed antennæ, the unmistakably crustacean mouth-formula, the sharp division into thorax and abdomen, show the isopods to be crustacea above *Apus*. Hence I cannot help thinking that they are related to the trilobites, not directly, but indirectly through *Apus*.—June, 1894.]

Discussion.

The President complimented the Author on the clear manner in which he had shown the homologies between the ancestral form *Apus* and the trilobita. He called attention to W. S. MacLeay's 'Observations on Trilobites,' published in 1839, in which MacLeay had proposed to place the trilobita between the entomostraca and xiphosura on the one hand and the isopoda and amphipoda on the other. He thought that MacLeay deserved credit for his acute insight into the relations of these forms, and that, too, at a time when but

[1] W. S. MacLeay, 'Observations on Trilobites, founded on a Comparison of their Structure with that of living Crustacea,' in Murchison's 'Silurian System,' pt, ii. 1839, pp. 666–669.

little advance had as yet been made in the study of the arthropoda. While he agreed with Mr. Bernard that the earlier trilobites presented forms with very numerous segments, he pointed out that the later ones showed signs of advance—in having fewer free thoracic rings and a well-developed pygidial shield. He had always cherished the idea that the isopoda might have branched off at some distant time from the trilobita, and he drew attention to such points of structure as the pores in the free cheeks, which were present in such isopods as *Sphæroma* and *Serolis*, and in such trilobites as *Phillipsia*, *Griffithides*, *Ampyx*, and *Trinucleus*. The way in which the neck-segment is folded around the glabella and forms the free cheeks in both isopods and trilobites must also be deemed significant.

The discovery of such well-preserved limbs, by Dr. Beecher, in *Triarthrus Beckii* justified the Author in regarding at least these earlier trilobites as extremely entomostracan in character.

The Rev. T. R. Stebbing agreed with the Author in thinking that the trilobites have little connexion with the isopods, though the resemblance is sometimes striking, and is often favoured rather than otherwise by the character and position of the eyes. But, whereas the isopods are distinctly malacostracan, with a number of segments never exceeding twenty-one, the number of segments in a trilobite varies as readily as the fashion of a lady's dress. Moreover, in many isopods the mandibles are stout and the limbs either strong or long and prominent, making it improbable that the body of the animal should be fossilized without leaving any trace of the appendages, as appears to have happened with the majority of the trilobites. On the other hand, *Apus* and *Lepidurus* seem to have still less claim to any close alliance with the trilobites, the two groups being quite devoid of any general resemblance, the phyllopods in question having a large carapace extending back over the segments of the thorax, on which the head-shield of the trilobite never encroaches. The tail or pleon of the trilobite is, as a rule, transverse and compact, that of the phyllopod elongate and flexible. Of the phyllopod limbs many are lamellar, while in Walcott's restoration of the trilobite *Calymene senaria* there is a continuous series of legs, all slenderly articulated. If mere guesses are allowable, the suggestion may be hazarded that of living animals the group nearest the trilobites may be the myriapods, as these have a long series of slenderly articulated legs, and segments both numerous and variable in number. The still prevailing obscurity of the subject is illustrated by the fact that Walcott compares certain appearances in his sections of Silurian trilobites with the spiral branchiæ of a whale-louse, a parasitic amphipod of probably quite modern development. In the figure of a specimen of *Triarthrus Beckii*, a pair of antennæ are represented projecting straight forward from the centre of the head-shield. It may well be wondered where the points of attachment of antennæ so placed are to be found on the underside of the trilobite's head.

Prof. G. B. Howes said that he believed the discovery of the terminal anus in the trilobite dealt the death-blow to the association

of the trilobites with the arachnoid series. He advanced reasons for accepting the Author's homology of the median cephalic pore of the trilobites with the aperture of the dorsal gland of *Apus*, and for believing that in the latter we are dealing with an organ early differentiated in the crustacean series, but now for the most part lost—the 'dorsal organ' of embryologists being its vestigial homologue. He believed that the facts and arguments brought forward by the Author of the paper proved the trilobites to be crustacea, and fully justified their association with *Apus* as an early offshoot on the crustacean line. He considered that in demonstrating the progressive fusion of head-segments among the trilobita the Author had shown those animals to have so far undergone a parallelism of modification to all other great groups of arthropods. If, as he believed, the degree of this fusion was the surest guide to the position of any one member in an arthropod series, that being the higher in proportion as the fusion is numerically the greater, the places customarily assigned to the Scorpionidæ and the Araneidæ by the advocates of the *Limulus*-an-arachnid theory must be transposed—the scorpions becoming the culminating members of the arachnoid series. Judged from this standpoint, the superficial resemblances between *Limulus* and *Scorpio* appeared to him closely akin to those between, say, the flying squirrels and *Galeopithecus*, or between the *Rana jerboa* and *Bufo jerboa* of Borneo, and suggestive of isomorphism by convergent modification. To definitely assert that *Limulus* is an arachnid appeared to him on a par with saying that the 'flying lemur' is a squirrel, and the *Bufo jerboa* a frog.

Mr. Malcolm Laurie also spoke.

The Author, in reply, said that none of the objections dealt with points of any morphological importance. The head-shield in *Apus* developed by backward prolongation into a carapace, and in the trilobites gave rise to the pleuræ by segmental repetition, as any prominent cuticular structure might be repeated. It was enough that the antennæ in both were inserted at the sides of the labrum, and that the trunk-limbs were of the same type, with 'endopodite,' 'exopodite,' and gills, and, what was still more important, with broad lines of insertion. That the trilobites might be myriapods could not have been seriously suggested. The subject was *necessarily* speculative, and the value of a speculation depended upon the evidence in its favour; in the present case, all the available evidence tended to establish the affinities proposed.

27. NOTE *on the Genus* NAIADITES, *as occurring in the* COAL FORMATION *of* NOVA SCOTIA. By Sir J. WILLIAM DAWSON, C.M.G., LL.D., F.R.S., F.G.S. With an APPENDIX by WHEELTON HIND, M.D., B.S., F.R.C.S., F.G.S. (Read February 21st, 1894.)

[PLATE XX.]

IN the autumn of 1892 Dr. Wheelton Hind was so kind as to invite me to place in his hands, for study and comparison, specimens of the bivalve shells from the Coal Formation of Nova Scotia, which I had described under the above generic name,[1] and some of which were described by the late Mr. Salter in the Quarterly Journal of this Society, vol. xix. (1863), under his new generic names *Anthracoptera* and *Anthracomya*. Owing to illness I was unable, at the time, to comply with Dr. Hind's request, and thus the Nova Scotian species lost the benefit of a detailed comparison with the British forms in Dr. Hind's excellent paper of May 1893.[2] I have now sent a collection of specimens to him, and beg to make the following remarks thereon.

These shells occur plentifully in some of the argillaceous shales of the Coal Formation, and occasionally on the surfaces of flaggy sandstones, but the most abundant repositories are the beds which I have named 'calcareo-bituminous shales' and 'bituminous limestones,' beds which, on account of their superior toughness and black colour, often stand out prominently in the coast-sections, and are sometimes almost entirely composed of these shells.[3] As none of the properly marine species of the Carboniferous Limestone ever occur in these beds, and as they are closely associated with the coal-seams, I have always been greatly interested in them—in connexion with the various theories of the deposition of coal. I referred to them in this relation in 'Acadian Geology,' 2nd ed. 1868,[4] in the following terms:—

"All the lamellibranchiate shells, which are so numerous in some of the shales and bituminous limestones of the Joggins that some of the beds may be regarded as composed of them, belong to one generic or family group. They are the so-called Modiolas, Unios, or Anodons of authors. I proposed for them, some years ago, the generic name of *Naiadites*,[5] and described six species from the Coal Measures of Nova Scotia, stating my belief that they are allied to Unionidæ, and that their nearest analogue may be the genus *Bysso-anodonta* of D'Orbigny, found in the river Paraná.

[1] 'Acadian Geology,' Suppl. 1st ed., 1860.
[2] Quart. Journ. Geol. Soc. vol. xlix. p. 249.
[3] See section of the South Joggins, in 'Acadian Geology,' 2nd and later editions.
[4] Pp. 202, 203.
[5] 'Acadian Geology,' Suppl. 1st ed.

Mr. Salter, however, to whom I sent specimens, regards these shells as belonging to his new genera *Anthracomya* and *Anthracoptera*, the former being supposed to be allied to Myadæ.[1] More recently Gümbel and Geinitz have described similar shells from Thuringia as belonging to the genera *Unio* and *Anodon*, and regard my *Naiadites carbonarius* (*Anthracoptera carbonaria* of Salter) as a *Dreissena*.[2] In the present uncertainty as to their genuine relations I shall retain the name *Naiadites* for the whole of the species, giving, however, Salter's generic names in brackets."

In correspondence with Mr. Salter at that time, I had pointed out that these shells were probably freshwater, and objected to his name *Anthracomya* as expressing an incorrect view of the affinities of the shells that I had sent to him; assigning the following among other reasons, afterwards published in 1868 in a new edition of 'Acadian Geology' along with descriptions and figures of the principal species, seven in number:—

(1) Under the microscope these shells present an internal lamellar and subnacreous layer, a thin layer of prismatic shell, and an epidermis, all corresponding to similar structures in the Unionidæ.

(2) The ligament was external; there seem to have been no teeth. The shell was closed (or slightly open) posteriorly, and in some species there are indications of a byssal sinus. The general aspect is in some species that of *Unio*, in others that of *Mytilus*. The wrinkling of the epidermis seems to be, for the most part, an effect of pressure.

(3) I know of no instance of the occurrence of these shells in the marine limestones, or associated with species unquestionably marine.

(4) The mode of their occurrence precludes the idea that they were burrowers, and favours the supposition that they were attached by a byssus to sunken or floating timber.[3]

(5) The attachment of *Spirorbis* to the outer surface of many specimens seems to show that they were free in clear waters.

On these grounds, and being unable from the specimens in my possession to make out evidence of generic distinctness, I continued to use the name *Naiadites* in preference to adopting the newer names suggested by Mr. Salter. Under this name I have described seven species from the Coal Formation of Nova Scotia, and have now sent specimens of these to Dr. Wheelton Hind for examination and comparison.

I may add that I do not object to the division of the species into two or more genera, for one of which Salter's name *Anthracoptera* should be retained. I doubt, however, whether these can be distinguished by form alone, which in most cases is all that we have

[1] Quart. Journ. Geol. Soc. vol. xix. (1863) p. 80.

[2] Neues Jahrb. 1864, pp. 646, 651, and Geol. Mag. 1865, p. 204.

[3] Dr. Hind informs me that a specimen in the British Museum (Nat. Hist.), at South Kensington, has the byssus preserved. [This specimen consists of a piece of fossil wood, round which numerous individuals of *Anthracoptera* are clustered in several rows, as they would be if attached by a byssus.—W. H.]

to depend upon. The species seem also to have been very variable, and they present very different appearances in different states of compression.

I may also mention that Dr. Wheelton Hind has been led into an error in supposing that *Estheria Dawsoni*, described by Prof. T. Rupert Jones, F.R.S., in the Geol. Mag. for 1870, may be the same with my *Naiadites lævis*. These shells are quite distinct in forms, markings, and structure, and occur at very different positions in the Carboniferous. *N. lævis* has been found only in a flattened state: its epidermis is strong and wrinkled, and the shell shows traces of prismatic structure.

The associates of *Naiadites* in the admirably exposed sections of the Nova Scotian coal-field, at the South Joggins and Sydney, Cape Breton, are various species of minute bivalve crustaceans, Eurypterids, *Anthrapalæmon*,[1] scales and teeth of ganoid fishes, and *Spirorbis*. The beds also hold much carbonaceous matter and fragments of fossil plants, often with *Spirorbis* attached. In some cases the beds of *Naiadites*-shale form the roofs of small coal-seams. In a few they have been elevated into soils and have been pervaded with *Stigmaria*-roots, thus resembling underclays. Their whole conditions point to land-locked ponds or lagoons, or to sluggish creeks. From the continuity of the beds these would appear sometimes to have been extensive, and, in addition to the animals already referred to, they were visited by ganoid fishes of large size, of the genus *Rhizodus*, and by small sharks of the genus *Diplodus* (*Oracanthus*). They were also tenanted by the aquatic batrachians of the period.

As the supposition that the shells of *Naiadites* were marine has placed them out of relation with their associates in the Coal Formation of Nova Scotia, it is a source of gratification to me, and an important contribution to the theory of coal, that their true affinities have now been so ably illustrated by Dr. Wheelton Hind.

Appendix.

Through the courtesy and kindness of Sir J. William Dawson I have been favoured with a perusal of his 'Note on the Genus *Naiadites*,' and have carefully examined at his request a series of shells from the South Joggins, as well as a series from the collection of the Geological Survey of Canada, forwarded to me for that purpose.

From an examination of these specimens it is easy to understand Sir William's attitude in considering it impossible to discriminate with any certainty between the different genera of shells in the South Joggins coal-field. They were all more or less crushed in the shale, and therefore showed no interiors, and often the proper external characters were masked. I am quite of the opinion now, from the knowledge I have obtained by a long familiarity with nearly perfect forms, that the genus *Naiadites* contains three distinct genera, for one of which the name must be retained. These three genera are the same as those which generally occur in our Coal

[1] *A. Hilliana*, Geol. Mag. 1877, p. 56.

Measures, a fact which was recognized by the late Mr. Salter, who, in a description of Sir William Dawson's shells, Quart. Journ. Geol. Soc. vol. xix. (1863), substituted the names of his newly-erected genera *Anthracoptera* and *Anthracomya* for *Naiadites*, notwithstanding the critical objections raised by the author of the name *Naiadites*.

I have been in correspondence with Sir William on the subject, and propose to retain the name *Naiadites* for the form called *Anthracoptera*.

In my paper published in this Journal, vol. xlix. (1893), p. 249, I figured and showed that Salter's *Anthracoptera* had a striated hinge-plate, a character, the absence of which had been considered to separate the genus *Myalina* (De Koninck), and in Geol. Mag. 1893, p. 514, I published a note on *Myalina crassa*, pointing out that there were no anatomical features by which the shells known by that name could be separated from Salter's *Anthracoptera*, at the same time noting that the septa within the beaks described by De Koninck were absent. On looking up De Koninck's original description and figures I find in 1842 ('Descript. des Animaux Fossiles,' p. 125) the following description :—"À l'intérieur et immédiatement au-dessous de ceux-ci [the umbones], une petite lame septiforme, semblable à celle que l'on observe dans certaines espèces de *Mytilus*." The figure given is too imperfect to show these characters. In his more recent work, 'Faune du Calcaire Carbonifère,'[1] he describes the genus and says it is "muni d'une cloison intérieure," but the figures, especially figs. 5, 7 and 9, pl. xxix., demonstrate most conclusively that this septum did not exist in them.

Prof. King ('Permian Fossils,' pl. xiv. figs. 5, 7 & 12) shows shells from the Permian which appear to possess this myophorial septum, to which he gave the names *Mytilus squamosus* and *M. septifer*, but in the text he suggests their reference to De Koninck's genus.

M'Coy ('Brit. Palæozoic Foss.' p. 492) says, in his description of *Myalina*, that there is "a triangular septum in the cavity of each beak, parallel with the plane of the lateral margins, leaving deep slits under the beaks of the cast," but he mentions no specimens from the Carboniferous series. When in the Brussels Museum a few months ago I was unable to see any signs of the septa in De Koninck's specimens, and think it probable that many of his forms will have to be placed with *Naiadites*, the name *Myalina* being retained for the septiferous forms from the Permian, and for any which may appear in the Lower Carboniferous series.

[It has been thought advisable, at the suggestion of the Council and with the assent of the author, to incorporate here the following synonymy of *Naiadites*.—Ed.]

[1] Ann. Hist. Nat. Musée roy. de Belgique, vol. xi. 1885.

SYNONYMY OF *Naiadites*.

1840. *Naidea*, Swainson, for *Unio*-like molluscs.
1845. *Naidea*, Buckman, 'Geology of Cheltenham,' Rhætic and Stonesfield plants.
1845. *Naiadita*, Brodie, Fossil Plants (in 'Fossil Insects').
1850. *Naiadita*, Buckman, adopted in Quart. Journ. Geol. Soc. vol. vi. p. 415.
1853. Dawson figured several Molluscs from Nova Scotia resembling *Modiola* and *Unio*, Quart. Journ. Geol. Soc. vol. x. (1854) p. 39.
1854. *Naiadites*, Morris, for *Naidea* and *Naiadita*, in his 'Catalogue of British Fossils.'
1855. Dawson again figured one of these molluscs as a *Modiola*, 'Acadian Geology,' 1st ed. p. 148.
1860. Dawson gave a short description of the shells and referred to the above figure, provisionally naming it *Naiadites*. He described also several species; the first and type species being *Naiadites carbonarius*. Supplement to 1st ed. 'Acadian Geology,' p. 43.
1861. Salter gave the name of *Anthracomya* to certain British Coal-measure molluscs with full descriptions and figures, Mem. Geol. Surv., 'Iron Ores of Great Britain,' pt. iii. p. 229.
1862. Salter speaks of three species of *Naiadites* he had received from Dr. Dawson, namely *Naiadites elongatus*, *N. carbonarius*, and *N. lævis*. The first and last of these he refers to *Anthracomya*, and for the other, *N. carbonarius*, Dawson's type, he proposes the name "*Anthracoptera* for these triangular shells."

If the name of '*Naiadites*' can be retained for any of these molluscs it must be for this type-species *N. carbonarius*, for which Salter erroneously proposed the generic name of *Anthracoptera*, Quart. Journ. Geol. Soc. vol. xix. (1863) p. 80.

Note.—Wheelton Hind, 1893 (see below), says that the form figured by Salter, Quart. Journ. Geol. Soc. vol. xix. p. 79, fig. 3, as *Anthracoptera carbonaria* is not the same as Dawson's type, 'Acadian Geology,' 1st edit. p. 148, and Quart. Journ. Geol. Soc. vol. x. p. 39.

1868 & 1878. Dawson gives figures and descriptions of these Nova Scotian shells and partially adopts Salter's names as sub-genera for some of the species, thus: *Naiadites* (*Anthracoptera*) *carbonaria*, *Naiadites* (*Anthracomya*) *elongata*, *Naiadites* (*Anthracoptera*) *lævis*; but speaks against Salter's idea of the marine nature of these shells (as quoted above, p. 436), 'Acadian Geology,' 2nd & 3rd edit. p. 202 *et seqq.*
1893. Wheelton Hind adopts Salter's two genera *Anthracomya* and *Anthracoptera*, for the British species, but says that the specimen from Nova Scotia figured by Salter as *Anthracoptera carbonaria* is not the same as Dawson's *Naiadites carbonarius*; the latter, Hind says, is an *Anthracomya*, Quart. Journ. Geol. Soc. vol. xlix. (1893) p. 249.
1894. Wheelton Hind in the MS. of the present paper proposed to adopt *Naiadites* for *Anthracomya*, and to retain the name of *Anthracoptera* for the type-species of *Naiadites*. He now acknowledges that Salter's *Anthracoptera carbonaria* is the same as Dawson's *Naiadites carbonarius*. The genus *Naiadites*, therefore, will have to be used and *Anthracoptera* discarded. The British forms referred to the latter genus, in the author's 1893 paper, will now be called *Naiadites*.

I must admit the error of which I am convicted by Sir William Dawson—namely, that I confounded *Naiadites lævis* and *Estheria Dawsoni*—the more so as the fault was due to carelessness in comparing the numbers of quoted pages.

I am not able to state that any of the species submitted to me are the same as British forms, therefore the specific names must still remain, though, if at any time in the future more perfect specimens are obtainable, it may be quite possible to do so.

I have a series of specimens from the South Joggins labelled by Sir J. William Dawson *Anthracoptera carbonaria*. They existed in very large numbers in some of the shales of the South Joggins, so much so that the greater part of the mass is composed of débris of this shell, with entomostraca and vegetable remains. I have little or nothing to add to Sir William's original specific description, but would point out that his original figure is very misleading, and that *Naiadites carbonarius*, Dawson, differs much from the figure of *Anthracoptera carbonaria*, Salter (Quart. Journ. Geol. Soc. vol. xix. 1863, p. 79), and it was this difference which led me to suppose that Dawson's original specimen was probably *Anthracomya* (Quart. Journ. Geol. Soc. vol. xlix. 1893, p. 249). The umbones were not shown to be terminal, and were described as "acute in the anterior fourth of the shell," while I thought Salter's figure was that of a specimen of one of his *Anthracopteræ*.

I am bound to say that Salter's figure more nearly represents the shells which have been sent to me as *Naiadites carbonarius*. In shape this form approaches somewhat to that of *Naiadites* (*Anthracoptera*) *modiolaris*, but the umbones are more raised above the hinge-line, more pointed and not curved anteriorly at the apex.

There is one specimen which reveals a typical interior with finely striated hinge-plate, bevelled at the exterior of its outer edge, with trifid anterior muscular scars, and relatively larger posterior-adductor scar. The posterior end was often sinuated above. The periostracum shows the typical characteristics of the genus. There exists, as with us, an elongated form, probably only a variety of this shell; but it evidently comes from a different bed, the matrix being a hard, fine-grained, micaceous sandstone (Pl. XX. fig. 1). It would seem to have been less gregarious in its habit, if one may judge from the paucity of its remains in the specimens to hand.

It is very difficult to be absolutely sure as to the generic position of the shells figured as *Anthracomya elongata*, as there are no specimens showing the hinge-line, ligament, or muscle-scars, but from the shape they probably belong to this group. There is nothing to add to the original description, but I think that the sentence describing the position of the umbones is misleading. It says, "the beaks obtuse and more anterior," but it is difficult to see what is the meaning of the word *more*.[1] It cannot refer to the shell previously described, which is a *Naiadites* (*Anthracoptera*) *carbonarius*, and has its umbones very forward; while, comparatively to the length of the hinge-line, the umbones in *N. elongatus* are subcentral in the specimen figured.

There appear to have been two forms or varieties of this shell, one more elongate and comparatively narrower, the other short and as broad as long.

With regard to *Anthracomya arenacea*, the specimen which Sir J. W. Dawson has sent me is typical of Salter's genus; it is allied to the forms found on the Continent, and known as *Anodonta*

[1] [A clerical error for 'less.'—J. W. D., May 1894.]

Goldfussiana. The original drawing in 'Acadian Geology' does not show the gradually expanding posterior end, and would give the idea that the original was an *Anthracosia*. I think the specimen from the McGill College Collection labelled *Naiadites elongatus* belongs to this species. This specimen is nearly 1 inch long, and shows the typical shape and contour.

Naiadites angulatus (Dawson) I consider to be { *Carbonicola* / *Anthracosia* }[1], a pretty little form of typical shape. In the original drawing the posterior-superior angle is too much prolonged backward.

Anthracomya ovalis is a somewhat larger, more tumid shell than *Naiadites elongatus*, to which it approaches. I think that the shells in a block of Millstone Grit from Riversdale belong to this form; if so, it is interesting to note the presence of the same form in the Upper Coal Measures of the Joggins.

Anthracomya lævis is very similar to a shell which is obtained, only crushed flat, from the Wigan coal-field; the English specimens are, however, larger.

Prof. Amalizky has fallen into error as to the value of the term *Naiadites*, and in his work on the Anthracosidæ of the Russian Permian, 1892, has erected *Naiadites* into a genus of the new family Anthracosidæ, reserving the term for a set of shells totally different from the majority of those for which the name was invented. I have shown above that originally the genus included

Naiadites carbonarius.	*Anthracomya lævis*.
„ *elongatus*.	{ *Carbonicola* / *Anthracosia* } *angulata*.
Anthracomya arenacea.	
„ *ovalis*.	

I shall take an early opportunity of combating other views on this subject contained in Prof. Amalizky's work.

EXPLANATION OF PLATE XX.

Coal-Measure shells from the South Joggins. The figures are of the natural size, when not otherwise stated.

Fig. 1. *Naiadites*, sp. Elongate form. (Unfortunately the artist has inverted the figure.)
2. *Naiadites carbonarius* (Dawson).
3. „ „ showing interior. Muscle-pits.
4. *Anthracomya arenacea* (Dawson).
5. „ „ probably young.
6. „ „ probably young.
7. *Anthracomya elongata* (Dawson). ×2.
8. „ „ „ ×2.
9. „ „ „ ×2.
10. „ „ „ ×2.

[1] It is highly probable that the term *Anthracosia*, King, must give way to *Carbonicola*, M'Coy, on the ground of priority, although the latter's description of the hinge-plate is erroneous.

Fig. 11. Slab with (*a*) *Anthracomya elongata.*
(*b*) *Anthracomya*, sp.?
(*c*) *Naiadites carbonarius.*
(Collection of the Geol. Survey of Canada.)
12. *Anthracomya lævis* (Dawson).
13. *Anthracomya ovalis* (Dawson). Horizon of the Millstone Grit.
14. { *Carbonicola* (M'Coy) / *Anthracosia* (King) } *angulata* (Dawson).

[NOTE.—Specimens 1, 4, 5 belong to Sir J. W. Dawson's collection in the McGill College, Montreal; specimens 11 & 13 to the Geological Survey of Canada. The remainder have been presented to me by Sir J. W. Dawson.—W. H.]

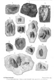
DISCUSSION.

Prof. J. F. BLAKE observed that the name *Naiadites* had been used by Buckman for a Liassic plant in 1845, and therefore was not available for a Carboniferous shell in 1862. As to the name *Anthracomya*, there is no more objection to it on the score of the shell not belonging to the Myacidæ than to the name *Goniomya* for shells belonging to the Anatinidæ.

Dr. W. T. BLANFORD said that one important point had apparently escaped Dr. Hind's notice. Mr. Salter, in the Society's Journal for 1863, retained the name *Anthracomya* in preference to *Naiadites*, because the latter genus had never been described. Names published without a description have, of course, no claim to recognition.

Dr. J. W. GREGORY pointed out that the use of a generic name in botany does not bar its subsequent use in zoology; as the botanists insist on using names previously used for animals, zoologists have no option but to do the same.

The PRESIDENT, Prof. T. MKENNY HUGHES, and Mr. MARR also spoke.



28. FURTHER NOTES *on some* SECTIONS *on the* NEW RAILWAY *from* ROMFORD *to* UPMINSTER, *and on the* RELATIONS *of the* THAMES VALLEY BEDS *to the* BOULDER CLAY. By T. V. HOLMES, Esq., F.G.S. (Read April 25th, 1894.)

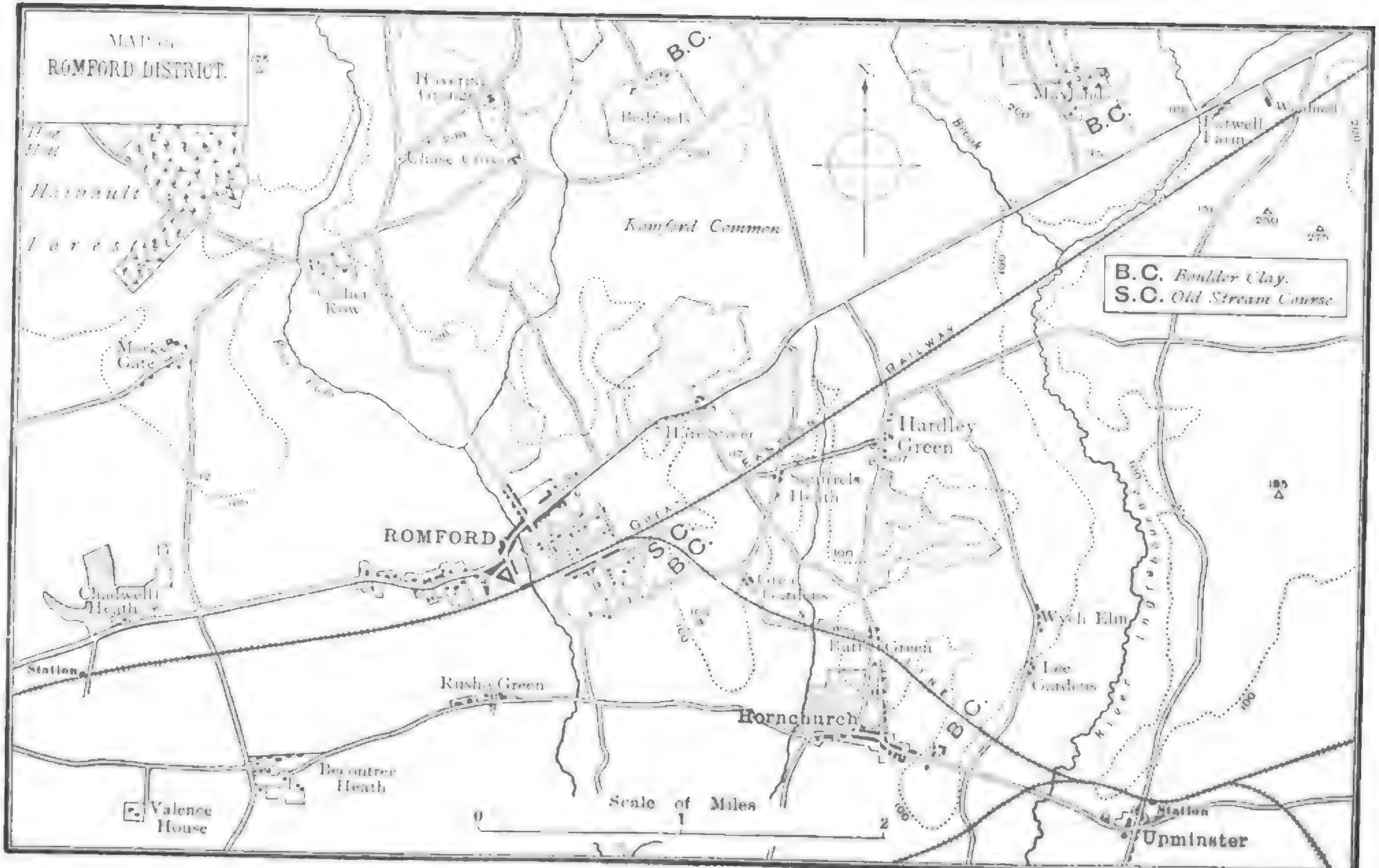
ON March 9th, 1892, I had the honour of reading a short paper before the Society on the sections seen along the course of this new railway, dwelling chiefly on the cutting north of Hornchurch,[1] in which a considerable mass of Boulder Clay had appeared, having a maximum thickness of 15 feet, and a horizontal extension of about 300 yards. The Boulder Clay lay in a slight hollow on the surface of the London Clay, and was covered by gravel belonging to the highest terrace of the Thames Valley system in the district, the surface of which varies from 90 to 120 feet above Ordnance datum.

At that time, and during many months afterwards, but little work was done in the cuttings nearer Romford than that just mentioned. The cutting at Butts Green and the more northerly excavation between Great Gardens and the junction with the Great Eastern Main Line at Romford remained in an almost stationary state. During the period between the spring of 1892 and that of 1893 I visited these cuttings many times, though without detecting anything but London Clay and gravel: more London Clay being visible at Butts Green than nearer Romford. However, last year the Romford cutting was considerably widened and deepened, and afforded sections of much greater interest than I had anticipated.

The new railway joins the main line about ½ mile north-east of Romford station. The main line ranges in a north-easterly and south-westerly direction, that of the new railway is from south-east to north-west. Sixty or seventy yards south of the main line, the new railway passes under the Victoria Road, which is parallel with the G.E.R., thence to Romford station. At another point about 600 yards to the south-east the new line passes beneath the Brentwood Road. The two roads just mentioned meet together at a point a few yards south of Heath House, near Squirrel's Heath. The Romford cutting extends from the junction to a point south of Great Gardens, but is of especial interest only in the space between the two roads just mentioned.

On April 25th, 1893, I noticed that the navvies who were at work 40 or 50 yards south of the Victoria Road bridge were throwing up into the waggons some dark material apparently less stiff and more loamy than London Clay. On Saturday, April 29th, I found the cutting free from workmen and waggons, and a clear vertical section exposed on its eastern side, from the bridge southward, for a distance of about 90 yards. Close to the bridge was London Clay, 8 or 9 feet thick, covered by a nearly equal thickness of gravel; but

[1] 'The New Railway from Grays Thurrock to Romford: Sections between Upminster and Romford,' Quart. Journ. Geol. Soc. vol. xlviii. (1892) p. 365.

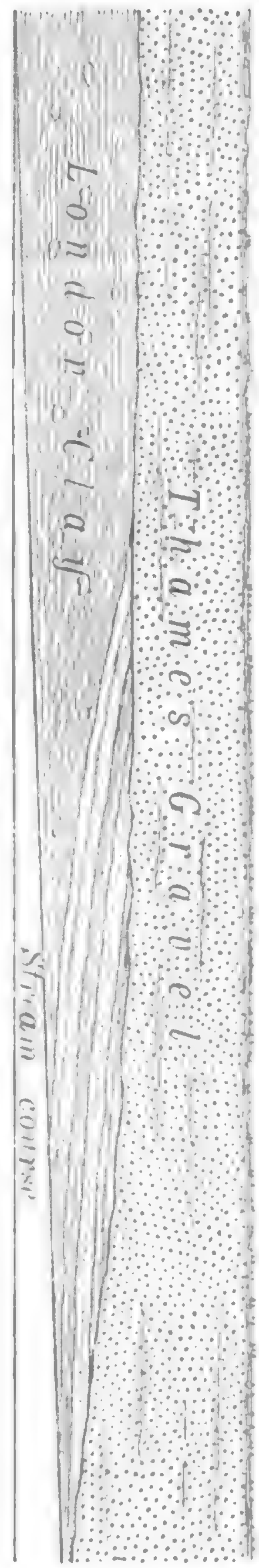

MAP OF
ROMFORD DISTRICT
B.C. Boulder Clay.
S.C. Old Stream Course.
B.C.
Romford Common
RAILWAY
ROMFORD
Hardley
Green
Wych Elm
Hornchurch
Rush Green
Chadwell
Heath
Station
Valence
House
Upminster
Station
Scale of Miles
0
1
2

about 35 yards from the bridge the London Clay began to disappear, its place being gradually occupied more and more by dark silt with interbedded sand and small pebbles, and the Thames Valley gravel still forming the surface. At a distance of 60 yards from the bridge this silt and sand occupied the whole of the space between the surface-gravel and the bottom of the cutting. And at 85 yards the gravel, which had been gradually encroaching upon the silt, came down to the bottom of the cutting, which was not so deep by about 3 feet as at the bridge, and gravel only could be seen southward of that point.

The section was so clear that the northern boundary of this silty deposit was perfectly distinct, though its former extension southward could not be ascertained owing to the erosion which had taken place during the deposition of the overlying gravel. It appeared to me to be a fragment of the silted-up channel of an ancient stream-course. This old stream-course must have been of considerable size, as more than 80 yards from the bridge the inclination of the beds was still southerly, as though the centre of the channel had not been reached. On the opposite side of the cutting material of the same silty character could be abundantly seen, but the section had been obscured by having been sloped. All, therefore, that can be said as to the direction of the channel is that apparently it was about east and west. Among the small pebbles visible here and there were many of Chalk, and it seemed to me that the contents of this old silted-up channel had been very largely derived from the Boulder Clay. But no fossils could be seen to indicate fluvial, estuarine, or any other conditions.

Section in the Romford cutting, south of Victoria Road Bridge.

N.W.



S.E.

Vertical scale: 1 inch = 20 feet. Length about 80 yards.

I next visited this cutting on May 11th, 1893, in the company of Messrs. W. Whitaker and H. W. Monckton, whom I had asked to visit Romford in order to see the silted-up channel just described.

But since April 29th the cutting had been widened and sloped, and though plenty of material such as I have mentioned could be seen, the boundaries of the channel, and its relations to the London Clay and the gravel, had been utterly obscured. However, there seemed to be traces of Boulder Clay near the channel, and, on walking southward, we discovered on the western side of the cutting, at a distance of rather more than 100 yards north of the Brentwood Road, a considerable mass of Boulder Clay traceable horizontally for more than 30 feet in the sloped side. It was in every respect average Boulder Clay, like that seen at Hornchurch, and in it we found a piece of Kimeridge Clay containing *Lucina minuscula*. Similar fragments were seen in the Hornchurch cutting. This Boulder Clay was on precisely the same level as that at Hornchurch, and was similarly covered by gravel belonging to the Thames Valley system. It was nearly 1½ mile north-west of the Hornchurch Boulder Clay.

The relations between the Boulder Clay and the silted-up channel could not be ascertained, as the cutting had been sloped, and they appeared in different parts of it and not in contact. But Mr. Whitaker was disposed to think that the silty material was probably of Glacial age.

The finding of the Boulder Clay at Hornchurch left the nature of the hollow in which it had been deposited an entirely open question. The additional Boulder Clay of the Romford cutting at precisely the same level, and also covered by gravel of the highest, and presumably oldest terrace of the Thames Valley system, tends to show that both were deposited in a broad valley belonging to some drainage-system more ancient than that of the present Thames. It appears to me that considerable light may be thrown on the probable course of this ancient drainage-system by a brief investigation into the distribution of the Boulder Clay towards its southern limits, and by the leading features in the physical geography of the district.

North and north-west of Romford a tract of high ground, rising in places to a height of more than 300 feet above Ord. dat., lies between that town and the valley of the Roding. Towards the north-east, from Warley through Billericay and Danbury, and in Tiptree Heath, north of the Blackwater, we have also an elevated district. However, along a line nearly parallel with that from Warley to Danbury, but from 3 to 4 miles southward, we find a belt of low-lying country, mostly less than 100 feet in height, and much of it below 50 feet. South of this lowland tract there is more high ground at Laindon Hills, Hadleigh, Rayleigh, and Althorne, with a general trend nearly parallel with those of the areas of high and low ground just mentioned, though the Thames has now caused a breach of continuity between Laindon Hills and Hadleigh, and the Crouch has made a similar breach between Rayleigh and Althorne.

On comparing maps showing the geology with others illustrating the physical geography of the district, we find that the Boulder Clay comes as far south as the edge of the high ground between Warley

and Danbury which overlooks the valley between those places and Laindon, Hadleigh, and Rayleigh. North and north-west of Romford, around Havering-atte-Bower and Chigwell Row, there is little, if any Boulder Clay at a level lower than 200 feet above the sea, except at Maylands, on the western flank of the valley of the Ingrebourne. In a broad and general way it may be stated that the height at which the Boulder Clay exists diminishes as we travel from the west eastward. Thus, towards the southern edge of the high ground between Warley and Danbury, it may be seen here and there below the 200-foot contour line at heights from about 170 feet upwards; and no Boulder Clay whatever is visible on the top of the ridge of Tiptree Heath, though it appears in the low ground north-west of the ridge.

Turning to the river-valleys, we may note that though the Boulder Clay keeps, as I have said, to ground of 200 feet and upwards at Havering-atte-Bower and Chigwell Row, yet it may be seen 40 or 50 feet lower in the valley of the Roding, to the north-west, and in that of the Ingrebourne at Maylands. Eastward, around Chelmsford, it appears at various levels between 100 and 200 feet, also about Hatfield Peverel and Witham. And in the river-valleys between Chelmsford and Maldon it descends here and there even below the 100-foot contour-line.

Thus in the existence of Boulder Clay in the valleys of the Roding and of the Ingrebourne near Romford, and in those of the Blackwater and its tributary streams around Chelmsford and Maldon, we have evidence of their excavation, to some extent, before the deposition of the Boulder Clay. And as the height at which Boulder Clay appears in these valleys decreases eastward, we have reason to believe that the drainage of this district took, as it now does, an easterly course at the time of the deposition of the Boulder Clay.

Assuming then, as seems most probable, that in the silted-up channel at Romford we have that of an ancient river, it is obvious, in the first place, that it must have belonged to an earlier system than that of the present Thames Valley, as it is manifestly older than the oldest Thames Valley gravel; secondly, that the Roding and Ingrebourne must have been among its tributaries, as is shown by the lower level of the Boulder Clay south of Romford than in the valleys of those streams; and, thirdly, that this Romford river flowed in an easterly direction. We have now to consider its probable course eastward.

I think there can be little doubt that, granting the above hypothesis, the course taken by the ancient stream disclosed in the Romford cutting was through the broad tract of low ground between the heights of Warley, Billericay, and Danbury on the north, and those of Laindon, Hadleigh, Rayleigh, and Althorne on the south. Crossing the present valley of the Crouch, it entered that of the Blackwater about midway between Woodham Ferris (or Ferrers) and Althorne (where the water-parting between the basins of the two streams is now only a little more than 50 feet above the sea), and joined the Blackwater somewhere east of Maldon.

The denudation which has separated this once broad, simple valley into three parts, drained respectively by the Mardyke, the Crouch, and the Blackwater, is of very much more recent date. Let us take the case of the Mardyke. At North and South Ockendon, west of Bulphan Fen, there is a broad expanse of Thames Valley gravel, the eastern boundary of which is close to those villages. This gravel must at one time have ended against higher ground, a little eastward of its present limits. But it now forms a plateau, the highest point of which is 110 feet at North Ockendon, and 79 feet at South Ockendon, while eastward we see a tract of ground about 3 miles in breadth which seldom attains a height of 30 feet. A similar examination would show that the separation of the valley of the Crouch from those of the Mardyke and the Blackwater was of equally recent date.

At length, on my hypothesis, the Thames, locally eating its way northward, eroded away the high ground intervening between itself and the Romford stream, and thus tapped the latter's water-supply and altered the course of the drainage. Fortunately a fragment of the silted-up and superseded stream-course was preserved. The course taken by the Thames in its most ancient days, east of Hornchurch, is clearly indicated on the Geological Survey map, in the deposits of gravel and loam shown at North and South Ockendon, Chadwell, Mucking, and Corringham. And I think there can be little doubt as to the correctness of Mr. Whitaker's view that in the patches of gravel and loam, stretching from Leigh and Southend, through Canewdon, Burnham, and Southminster to Bradwell, we have deposits formed on the western bank of the ancient valley of the Thames.[1]

In the discussion on my former paper, Mr. Hudleston pointed out that the discovery of Boulder Clay at so comparatively low a level as that of the Hornchurch cutting raised a question as to the possibly pre-Glacial age of the Thames Valley. On the other hand, the position in which the Boulder Clay was found, beneath gravel belonging to the highest, and presumably oldest terrace of the present Thames Valley system, seemed to show that the valley into which it had descended was hardly that of the present Thames. Consequently, the discovery of Boulder Clay near Romford on precisely the same level, and covered by gravel of the same age as that at Hornchurch, together with the silted-up fragment of an ancient river-channel of pre-Thamesian age, enables us to reconcile without difficulty these apparently antagonistic considerations.

It has, however, been doubted whether the valley of the Lower Thames shows any signs of the ordinary terraced arrangement usually found in river-valleys. For my own part I have detected nothing abnormal in that respect, possibly because, when a worker on the Geological Survey, it very frequently became my duty to map river-terraces in rocks of very varying degrees of hardness; while

[1] Geol. Surv. Mem. 'The Geology of London and of Part of the Thames Valley,' 1889, vol. i. p. 476.

work of this kind is seldom likely to be undertaken by a geologist except as a matter of official duty. On traversing the ground between Romford and Hornchurch and the Thames, I have never felt surprised to find that a terrace at a given height could be traced only for a few yards. Indeed, the material in which the terraces are cut being London Clay, it seemed to me that nothing else could be expected. For I remember, when in Cumberland, trying to map some terraces on the Eden some 3 miles below Carlisle, and failing to do so for more than a few yards in each case, because they were cut in sandy, earthy, and clayey gravel belonging to the Glacial Drift. On the other hand, 8 or 9 miles away, in the valley of the Esk about Netherby, in a similar lowland, drift-covered country, and on the banks of a stream of size and velocity like the Eden, terraces were easily traceable throughout their course. But on the Eden, below Carlisle, the harder rock underlying the Glacial Drift rose perhaps 5 or 6 feet above the level of that stream, while on the Esk, in the district above mentioned, it might be seen at a height of more than 20 feet above the river. Similarly, on the Thames terraces are frequently distinct where it flows through the Chalk, as at Henley and Remenham, and especially between Cookham and Maidenhead.[1]

Again, it was remarked during the discussion on my first paper on this new railway that the highest river-terrace was not *necessarily* the oldest. This remark is, of course, a perfectly true one, and, had I said that the highest terrace was *proved* thereby to be the oldest, would have been a useful and timely caution. But I have always felt that the word *proof* can scarcely ever be legitimately used in questions of this kind. We have to be content with a decided balance of probability. I need hardly remark that there is a strong general presumption that the highest terrace is the oldest, and that the lower terraces may be considered as later and later in date in proportion as they approximate to the level of the existing stream.

The Thames seems to me to show no signs of being an exception to the rule. A glance at the maps illustrating the geology and physical geography of South Essex shows how all probability is in favour of the view that the Thames, from the beginning of its existence, has, in this district, been occupied in cutting its way vertically from a height of more than 100 feet to its present level; while horizontally its course has been, in the main, southerly. In short, the available evidence seems to me amply sufficient to show that there are no grounds for regarding the Thames Valley as exceptional in the mode of its formation, and every ground for supposing the reverse. And I need hardly add that, where the stratigraphical evidence is as clear as it is in this part of the Thames Valley, it is almost impossible that it can be counterbalanced by any other considerations. Were we dealing with isolated patches of

[1] A map showing the terraces between Cookham and Maidenhead appears in Mr. Whitaker's memoir 'The Geology of London and of Part of the Thames Valley,' 1889, vol. i. p. 391.

gravel and loam, lying here and there on the surface of rocks of various ages, the evidence of any fossil remains they might contain might give a presumption of more or less weight as to their affinities. But where we have to consider a connected series of beds like those of the Thames Valley, we become entirely dependent on the stratigraphical evidence for information as to the persistence of any given forms of life, and should not allow mere *à priori* assumptions as to their continued existence, or the reverse, to have any influence whatever on our deliberations.

My former paper on the sections seen on the New Railway from Grays Thurrock to Romford was read on March 9th, 1892. On May 25th of the same year a very interesting paper, which I had not the good fortune to hear, was read by Dr. Hicks:[1] and this, from the conclusions favoured as to the age of what I take to be beds belonging to the Thames Valley system, demands a brief discussion here. We may well congratulate ourselves that so important a series of sections was brought under the notice of so eminent a geologist as Dr. Hicks; for, having been made in order to effect improvements in the sewerage, their existence was extremely brief, and might easily have been closed before any trustworthy recorder had had an opportunity of noting their character. From the full and well-illustrated account of these sections given by Dr. Hicks, we learn that they varied considerably in detail. In each case there was at the bottom an eroded surface of London Clay. Above this, here and there, where the surface of the London Clay was concave, was a thin stratum of dark clayey loam containing seeds, which bed, Dr. Hicks remarks, "appeared to pass almost insensibly into what was clearly deeply-stained London Clay with septaria." In this dark loam some mammoth-tusks were found (22 feet below the surface), also many seeds of plants living in marshy places or ponds and (according to Mr. Clement Reid) existing at the present time from the Arctic Circle to the South of Europe. Resting either on the London Clay or on the clayey loam was a bed of gravel of variable thickness; on the gravel, sand; and on the sand, clay with 'race,' flints, etc. The 'made ground' forming the surface seems to have varied usually from 6 to 10 feet in thickness.

The height of the surface where these sections occurred is about 80 feet above Ord. dat., or a few feet less if the 'made ground' be excluded. Any one who walks through the straight streets and open squares of the district in which these sections appeared cannot fail to notice the almost perfect flatness of the ground, which much resembles that of a broad expanse of old river-drift. And as consisting of a terrace of old river-deposits this district has been mapped by the Geological Surveyors.

Nevertheless, Dr. Hicks inclines to look upon these beds as probably older than the Boulder Clay, because the gravel, sand, and

[1] 'On the Discovery of Mammoth and other Remains in Endsleigh Street, and on Sections exposed in Endsleigh Gardens, Gordon Street, Gordon Square, and Tavistock Square, London,' Quart. Journ. Geol. Soc. vol. xlviii. (1892) p. 453.

clay containing 'race' resemble in their nature and arrangement the beds beneath the Upper Boulder Clay of Hendon and Finchley. But they seem to me to suggest with equal force the gravel, sand, and clay or loam which are the usual constituents of river-drifts, and the order in which these usually occur. 'Race,' again, may be found in clays and loams of the most diverse ages. In the chapters on the Woolwich and Reading Beds in Mr. Whitaker's memoir on the Geology of London 'race' is said to appear in clay or loam in at least ten different sections. It is also given as a constituent of the river-drift of the Thames Valley at Ilford, Erith, and Crayford. Thus its presence has no particular significance, and affords no presumption as to age.

Then there is the thin stratum of dark loam in which the mammoth-remains were found, and which appeared to pass insensibly into the London Clay on which it rested. This seems to me to be partly mud deposited in the channel of the river where the current was particularly sluggish, and partly material resulting from the contact of the river-water with the London Clay. Of course, a river is always tending to shift its course laterally. Thus a part of its channel where the current was once extremely sluggish gradually becomes the scene of more rapid motion, and gravel is deposited where once only mud in suspension slowly descended to the bottom. From the fact that gravel is usually the lowest of river-deposits we learn that any mud settling down where the current is sluggish is generally swept away when the current becomes swifter, and gravel is being deposited there. But here and there, in hollows, a little mud would be preserved, and the carcass of a mammoth, for instance, sinking into mud at the bottom of a river-channel would form an obstruction, resulting both in the deposition of an unusual thickness of mud and in the preservation of the animal's remains.

Again, the yellowish clay forming the surface-bed at and near Endsleigh Street, below the 'made ground,' seems to me to be the equivalent of the brick-earth of Ilford and other places in the Thames Valley which has yielded so many mammalian and other remains. I am aware that some geologists have shown an inclination to separate the brick-earths of the Thames Valley from the sands and gravels associated with them, on account of the fossil contents of the former beds. But it never appeared to me that there are any good grounds for such a proceeding. For they were all alike river-deposits formed contemporaneously, the gravel and sand having been brought down the river-channel, while the overlying brick-earth or clay was simply the inundation-mud which had spread over the adjacent flats in times of flood. And it seems obvious that an elephant or other large mammal, which had become drowned during a flood, would often be stranded on the alluvial flat, and his bones remain preserved by later deposits of mud, showing to observers of the present day every sign of tranquil deposition. On the other hand, creatures which continued to float down the river were extremely unlikely to have their remains preserved at all.

As the whole question thus turns on stratigraphical affinity, not upon a certain similarity in detail, it can hardly be doubted, I think, that the position of these Endsleigh Street beds is one in which river-drift would naturally be expected, and where the representatives of beds which exist 5 miles away, and 200 feet above the sea, certainly would not be. And this conclusion, that they should be classed as river-drift, has also the advantage of being in accord with the fossil mammalian evidence. For an old river-terrace, south of Euston Square, with a height of 70 to 80 feet above the sea, may well be nearly equivalent to another at Ilford, 9 miles lower down the river, at a height of 40 to 50 feet. And both in the Endsleigh Street district and at Ilford the remains of the mammoth have been found, together with those of the red deer and horse. But of course the Ilford pits, which cover many acres of ground and have been worked over during many years, have yielded many other mammals in addition.

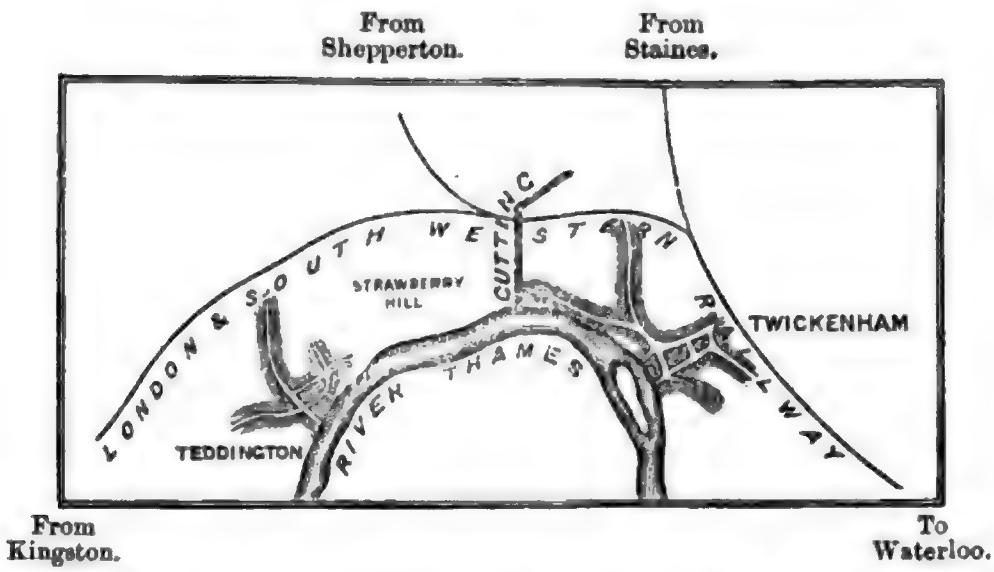
I trust, therefore, that Dr. Hicks will think that some reasons, at least, have been given here which should cause him to reconsider the conclusions to which he at present inclines as to the stratigraphical affinities of these Endsleigh Street beds. For my own part I would unhesitatingly class them as river-drift of the Thames Valley system, and consequently as post-Glacial in the sense of being of later date than the Boulder Clay of Essex and Middlesex.

[For the Discussion on this paper, see p. 460.]

29. *On the* Geology *of the* Pleistocene Deposits *in the* Valley *of the* Thames *at* Twickenham, *with* Contributions *to the* Fauna *and* Flora *of the* Period. By J. R. Leeson, M.D., F.L.S., F.G.S., and G. B. Laffan, Esq., B.Sc., F.G.S. (Read April 25th, 1894.)

In June 1892 excavations were begun for the construction of an effluent culvert from the Twickenham Sewage Works to the River Thames. The work was commenced at the foreshore of the river, near the celebrated Pope's Grotto. The Thames is a tidal river at that point, with a difference of about 8 feet between high and low water: the low-water line is 5 feet above Ordnance datum. The excavations commenced at low-water level on the Middlesex bank of the river, and were continued in a north-westerly direction, with an incline of 1 in 500, through certain roads and lands towards the Sewage Works. The length of the section was about one mile, and the width of the cutting was 4 feet 6 inches. The sloping bank between the river and the Kingston main road consisted of soft, loose material, which had evidently been deposited there in modern times. After crossing under the main road, distant about 60 yards

Fig. 1.—*Plan showing the position of the sewer-cutting in the Valley of the Thames at Twickenham.*



from the river, the excavation, which at this point was about 10 feet deep, entered into the reddish-yellow gravels which abound in this neighbourhood. It was then continued for some distance through these gravels under a roadway called Pope's Grove, at depths varying from 12 to 19 feet. A considerable quantity of water was found in the excavation, and had to be pumped. Beneath the gravels was the London Clay, which was met with in the excavation at two points, and in one place was penetrated to a depth of 5 feet.

After leaving the London Clay the excavation was continued through gravel alone for a short distance, and then a dark loamy

bed was found at the bottom of the cutting, about 12 feet below the surface of the roadway. The point where the dark bed was first touched was 420 yards from the river, and throughout the remainder of the section, which was continued through other roads, this dark bed was found more or less at or near the bottom of the cutting—at depths varying from 11 to 18 feet below the surface of the ground. At two points where 'sumps' were sunk for purposes of pumping, this dark bed was cut right through, and gravel in every way similar to that above was found beneath it. The thickness of the dark bed at these points was found to be 2 feet 6 inches and 2 feet 3 inches respectively, but it must have been thicker in some parts, for it was entered to a depth of 3 feet in one place without reaching the bottom.

In vol. xlviii. (1892) p. 453 of this Journal, a description is given by Dr. Hicks of a dark loamy bed found beneath the gravels in the bottom of excavations in the neighbourhood of Endsleigh Street in which organic remains were found. The bed itself appears to bear a resemblance to that found in the gravels at Twickenham; there is also considerable similarity in the flora found in each, as will be shown farther on, but the dark bed in Endsleigh Street was believed to lie directly on the London Clay. This clearly was not the case with the dark bed found at Twickenham; it intervened between beds of gravel, and was itself evidently of very limited thickness throughout.

The material composing the 'dark bed' found at Twickenham varied somewhat. In some places, especially where the bed attained its greatest thickness, it was of a soft, slimy nature, like river mud, whereas in other places it was much coarser and somewhat sandy in character. After exposure to the atmosphere the finer portions formed into compact clayey lumps, whilst the coarser parts became more disintegrated and had the appearance of earth or loam. It evidently contained a large proportion of decayed vegetable matter. When treated with water the finer samples left little or no residue, but from the others there was a considerable amount of sandy deposit. A chemical analysis gave the result tabled on p. 457.

Immediately above the dark loamy bed there appeared to be a layer of dark blue or greyish sand and gravel, which had very much the same appearance as the dredgings now taken from the river, and known as 'Thames ballast.' This layer of dark gravel was of varying thickness, and in some places was scarcely distinguishable, if not altogether absent. In no place did it attain any considerable thickness, and it appeared to die gradually away into the yellow or reddish gravel above it. It seemed as if the bed of dark loam had discoloured to some extent the gravel in contact with it. Throughout the gravels generally no organic remains were found, but the dark bed of loam was very rich in indications of animal and vegetable life. All the fossils found in the excavations were discovered either in the dark bed of loam or in the gravels immediately above it.

The annexed sections (figs. 2 & 3) show the structure of the ground in question and the position occupied by the dark-blue loam seam.

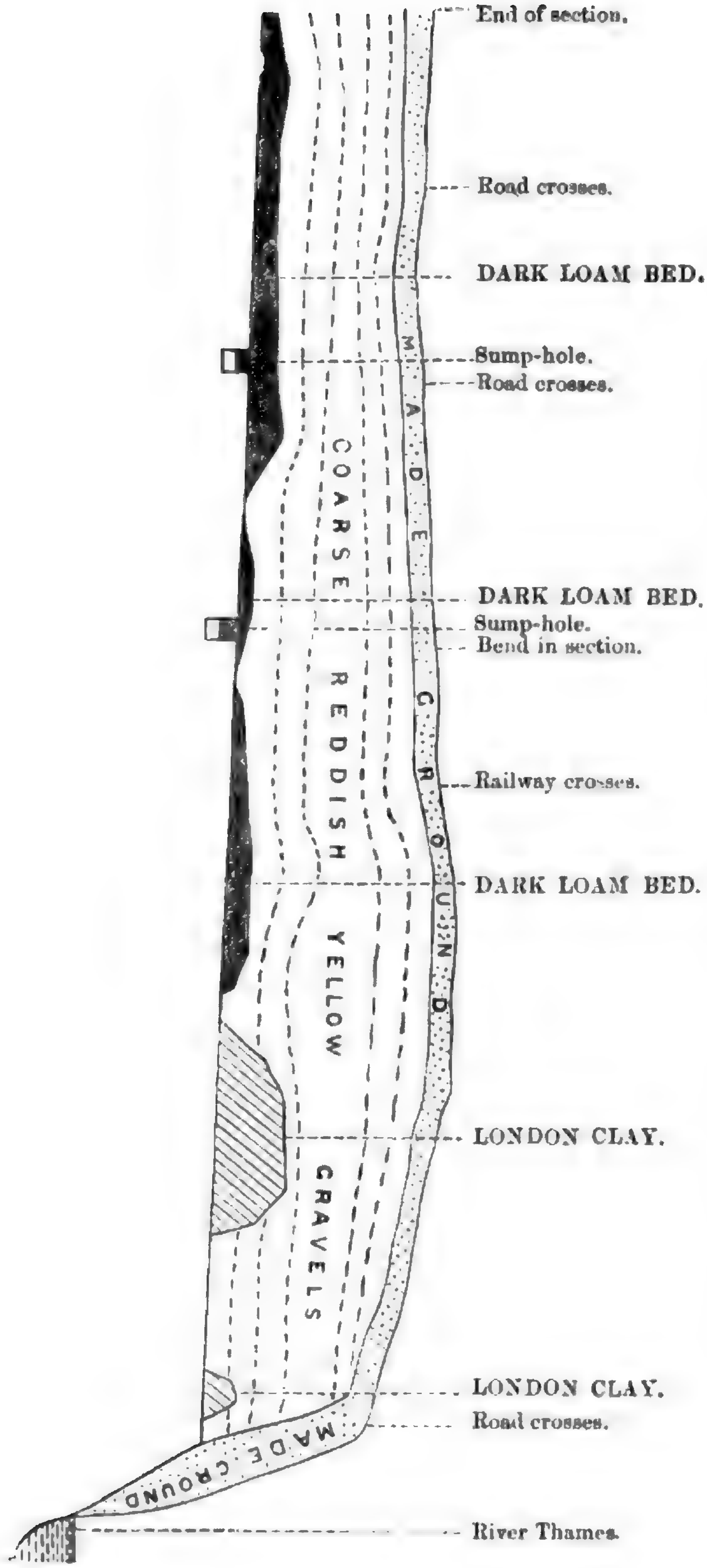
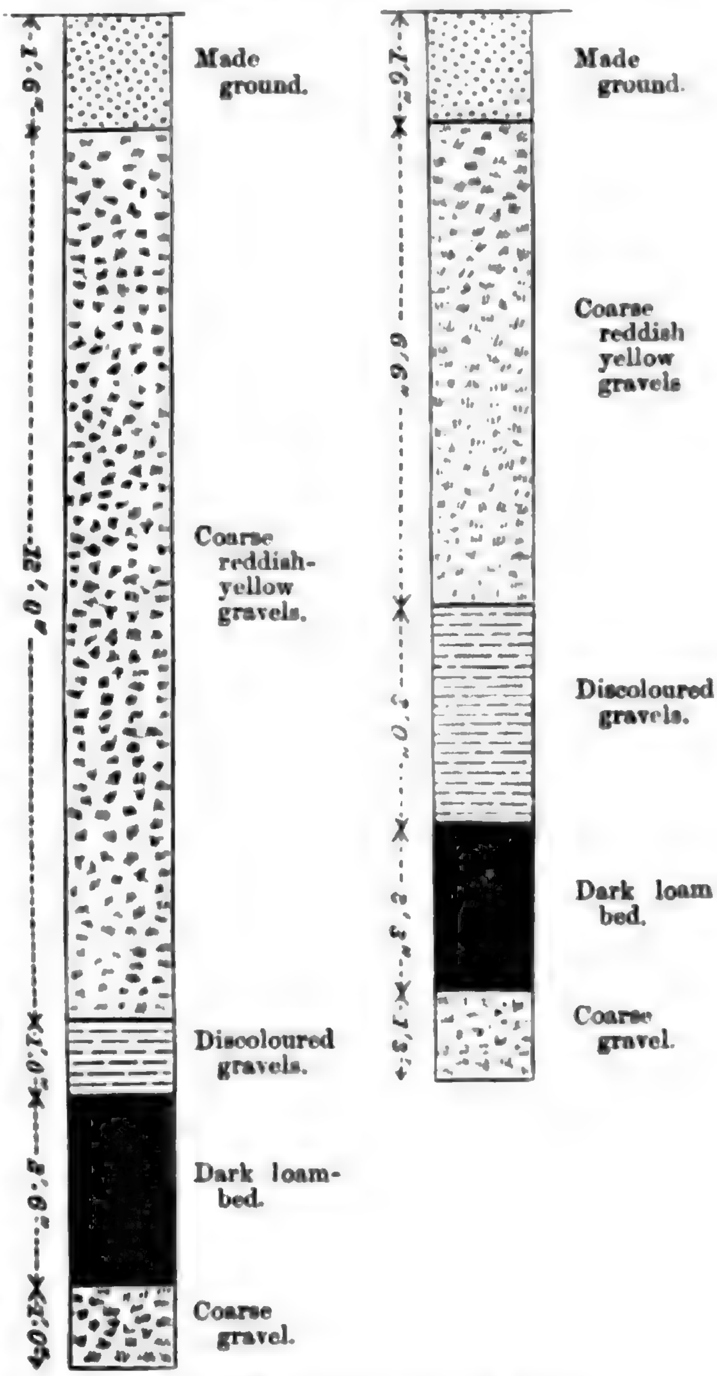


Fig. 2.—*Section of the sewer-cutting in the Valley of the Thames at Twickenham.*

Fig. 3.—*Sections of the sump-holes in the gravels at Twickenham.*



[Vertical Scale: 1 inch = 4 feet.]

There can be no doubt that this layer of dark-blue loam is purely a local one. In two well-sections at Isleworth, quoted in Whitaker's 'Geology of London,' Mem. Geol. Surv. 1889, vol. ii. p. 121, no mention of it is made; and, coming nearer home, we find that it is also absent in a recent well-section at Messrs. Burrows and Cole's Brewery, near Twickenham Railway Station, ½ mile east of the present section (*op. cit.* vol. ii. p. 170); while the description of an extensive cutting in the Thames Valley Railway, ½ mile to the westward (*op. cit.* vol. i. p. 394), does not mention anything about it. These facts, in conjunction with what will be shown farther on from the seeds found in the loam, appear to indicate that we are dealing with the deposit of a small local lake lying in the midst of the Thames gravels, while the fact of its erosion and its unconformability to the gravels above indicate that we are dealing later on with an old land-surface.

Our interest in the deposit was aroused by finding, in the first instance, reindeer-horns in the gravels, near the commencement of the cuttings. The London Clay then cropped up for some distance, and nothing more was found, till a ¼ mile farther on the bones of *Bison* and *Bos longifrons* (or *Bos taurus*) were discovered lying on the top of what proved to be our 'dark loam' layer. A diligent search was made in this loam for some further evidences of organic remains, but without success; and thinking that its dark colour

might be due to free carbon, a sample of it was submitted to Mr. William Chattaway, F.I.C., along with one from the lighter-coloured sand above, to see if any further light could be thrown upon it by the chemist. The subjoined analyses, together with Mr. Chattaway's remarks which accompanied them, showed that there was every reason for continuing our search for organic remains.

	A. Reddish-yellow Sand from above Dark Loam Layer, Pope's Grove, Nov. 1st, 1892.	B. Dark Loam Layer, Pope's Grove, Nov. 1st, 1892.
Moisture	·21 per cent.	11·68 per cent.
Combined water	trace.	·31 " "
Organic matter	·04 " "	2·36 " "
Silica	94·40 " "	65·11 " "
Ferric oxide	1·76 " "	1·28 " "
Alumina	2·73 " "	2·66 " "
Lime	·23 " "	8·78 " "
Magnesia	·16 " "	·40 " "
Soda and potash	trace.	trace.
Carbon dioxide (combined)	·19 " "	7·03 " "
Sulphuric anhydride	·26 " "	·33 " "
Chlorine	trace.	distinct trace.
	99·98 per cent.	99·94 per cent.

The following observations accompanied the analyses:—

(1) The lime is probably wholly present as carbonate in sample B; but in sample A it may probably be present as sulphate.

(2) The organic matter in B is largely carbonaceous, but Mr. Chattaway has not fully satisfied himself of its nature.

(3) There is probably only magnesium carbonate in the case of A, for, singularly enough, the amount of carbon dioxide found will exactly combine with the magnesia. That base is probably also combined with CO_2 in B.

(4) By 'combined water' is meant that which is not lost at a temperature of 100° C., but is held chemically, or else in some molecular way. This was of course determined by heating the sand to redness, and collecting the water in a tube packed with calcium chloride.

Later on we were abundantly rewarded by finding numerous shells, seeds, and much vegetable débris.

Extensive washings were made of the loam by Mr. H. M Bennett, and they were submitted to Mr. Clement Reid, F.L.S., F.G.S., who kindly determined them for us as follows:—

Mollusca from Twickenham.

Ancylus fluviatilis, Müll.	*Valvata piscinalis*, Müll.
Limnæa peregra, Müll.	*Pisidium amnicum*, Müll.
Planorbis albus, Müll.	—— *pusillum*, Gmel.
Bythinia tentaculata, Linn.	*Sphærium corneum*, Linn.

Plants from Twickenham.

Stellaria media, Cyr.	*Potamogeton rufescens*, Schrad.
Montia fontana, Linn.	*Zannichellia palustris*, Linn.
Heracleum Sphondylium, Linn.	*Eleocharis palustris*, R. Br.
Galeopsis Tetrahit, Linn.	*Scirpus lacustris*, Linn.
Atriplex sp.	*Carex panicea*, Linn.
Polygonum Persicaria, Linn.	—— sp.
Rumex crispus, Linn.	*Phragmites*.

The whole of the 8 species of mollusca and the 14 of plants are still living in the neighbourhood. They point, as Mr. Reid remarks, to swampy ground and a small pool or channel rather than to running water or any large stream.

Lying just upon the layer of dark loam were found scattered all along the section a great number of mammalian bones, about 300 altogether, which were carefully preserved and sent for determination to Mr. A. Smith Woodward, Assistant Keeper of the Department of Geology, British Museum (Nat. Hist.), to Mr. E. T. Newton, F.R.S., of the Geological Survey, and to Prof. Charles Stewart, P.L.S. The following species were identified:—

Bos longifrons.	*Sus scrofa*.
—— *taurus*.	*Cervus elaphus*.
Cervus capreolus.	*Canis lupus*.
Rangifer tarandus.	*Bison priscus*.

Much interest was aroused with regard to the bones of the *Bos*, Mr. Smith Woodward, Mr. Newton, and Prof. Stewart considering them to belong to *Bos longifrons*, while Prof. Boyd Dawkins, F.R.S., to whom some of them were sent, affirms them to be '*Bos taurus*, a domesticated variety larger in the horns than the actual strain of *Bos longifrons*.'[1]

A noticeable point in connexion with the femora and humeri, the marrow-bones of the bison, was that in most cases the bones were broken, and the shaft split or cracked as if from direct violence, and this suggested to Dr. Günther, F.R.S., of the British Museum

[1] [It having been objected that the Authors, when referring to the occurrence of the remains of *Bison priscus* and *Bos longifrons* lying on the top of the dark layer of loam, seem to convey the impression that the two animals were contemporaneous, whereas throughout the Thames Valley deposits *Bos longifrons* is always referred, and justly so, to a much later date than *Bison priscus*, the Authors of this paper wish, in reply, to state that they have no theory upon the subject. The bones were collected by the navvies, as they were found, according to their statements, just on the top of the dark loam-layer, and put into a sack until they were handed to the Authors. Whilst on the one hand there is no reason to doubt the accuracy of the men's statements, there is on the other no desire to elevate them to the standard of skilled observers: the facts must be taken for what they are worth.—May 15th, 1894.]

(Nat. Hist.), the work of human hands. It is a curious fact that only the marrow-bones had been so damaged, the more solid metatarsal and metacarpal bones (devoid of marrow) being undamaged and entire. The frontal bones of the *Bos* are all broken up in a definite and peculiar manner, and the cranial bones fractured into many small pieces, nor could any large toothmarks upon the bones be found which might have explained the fracturing as due to beasts of prey. Looking at the bones themselves, there would seem to be very little doubt that these fractures indicate the presence of man, were it not for the fact that Mr. Clement Reid has informed us that the same thing is frequently seen in the long bones of the Cromer Forest Bed, where the agency of man is out of the question. Nevertheless, it is exceedingly difficult for us to believe that so many bones could have been fractured in so definite and apparently purposeful a manner without enlisting the factor of human agency, especially as the presence of man in England at a time anterior to these deposits is not disputed.

No flint-implements, however, have been found in the Twickenham gravels, although carefully and constantly searched for. Yet they have been found in fairly large numbers dredged from the Thames in the immediate vicinity, along with the bones of animals now living, and are all of the Neolithic type; but the undisturbed gravels are quite barren in this respect.

Of the Twickenham seeds determined by Mr. Clement Reid, one half of the species are the same as those discovered by Dr. Hicks in Endsleigh Street (which were also determined by Mr. Clement Reid) and declared to characterize marshy places and ponds.[1] The mollusca are far more abundant at Twickenham, we having 8 species, whereas Dr. Hicks had only 2. The vertebrates are very different, *Cervus elaphus* being the only one common to both sections.

In connexion with the fauna of the district, and as throwing some light upon the conclusions at the end of this paper, we may mention here that the bones of rhinoceros have been found at Twickenham, 20 feet below the surface, in sand, at Messrs. Bennett and Hawkins's Nursery Grounds, in digging for a deep well; and 8 feet above them, that is 12 feet from the surface, were found the bones of the horse (*Equus caballus*). These would be ½ mile to the east of our present section, while ¼ mile still farther east the original specimen of the Saiga antelope (*Saiga tartarica*) was discovered in sand below the superficial gravel, 7 feet from the surface, and presented to the British Museum—it was the first evidence of the occurrence of this animal in Pleistocene Britain.

Conclusions.

The gravels at Twickenham which, up to the time of this cutting, have been regarded as uniform, indefinite, and almost destitute of organic remains, are now shown to contain a varied fauna and flora, suggestive of great climatic and other changes.

[1] Quart. Journ. Geol. Soc. vol. xlviii. (1892) p. 458.

They can be divided into four zones :—

(1) The lowest and deepest, the 'coarse ballast gravel,' which suggests a rapid torrent at the time it was laid down.

(2) The layer of 'dark sand,' sparsely scattered with gravel, which indicates a slackening of the stream.

(3) The dark-blue loam seam which points to a further slackening of the current, the plants and shells all now living in the neighbourhood and indicating a climate like the present.

The diminishing velocity of the stream in these three zones suggests a continuous lowering of the land, and may, therefore, point to the termination of a continental period.

There is evidence of an old land-surface, on the top of the blue loam seam, over which roamed the bison and the reindeer, and as these animals do not occupy the same areas at the same time, it points to a changing climate of long cold winters, during which the reindeer came south, and short hot summers, when the bison would move northwards.[1]

The bison-bones indicate the very probable presence of river-drift man.

(4) The overlying coarse reddish-yellow gravels, with (towards the bottom) reindeer bones only, and large flints such as could have been carried by ice alone, indicate a much colder climate, probably Arctic (a supposition which is confirmed by the Saiga antelope having been found in this layer in the same district in 1891).

Discussion (on the preceding two Papers).

The President congratulated the Authors of the second paper on having succeeded in rescuing so interesting a collection of remains of Thames Valley mammalia. He inquired if Dr. Leeson had obtained the remains of the Saiga antelope from the same horizon as the present 'finds,' and if so he pointed out that these remains—*i. e.* the *Bison priscus*, the *Rangifer tarandus*, and the Saiga antelope—represented the *older* fauna of the Thames Valley gravels and brick-earth.

Sir John Evans expressed his pleasure at Mr. Holmes's further discovery of evidence as to the superposition of the old Thames Valley gravels upon the Boulder Clay, as these discoveries supported the view he had always held, that these gravels, whether at a high or at a low level, were 'post-Glacial' in the sense indicated by the Author.

The finding of the mammalian remains by Dr. Leeson in the low-level gravels at Twickenham was of interest, as proving the existence of the reindeer and bison in the Thames basin at the time of the deposition of these beds. As to some of the remains of other animals, however, he entertained doubts whether, though found in the course of the excavation, they really belonged to the gravels.

Prof. T. McK. Hughes was pleased to hear Mr. Holmes bring forward such direct proofs that the mammoth-gravel of the Thames Valley was post-Glacial. He thought that the bones exhibited by

[1] See Boyd Dawkins, 'Early Man in Britain,' pp. 189, 191.

Dr. Leeson and Mr. Laffan might be divided into two groups, (1) those with bison, and (2) those among which the small ox and dog or wolf occurred. Group 2 he thought might be further distinguished as (*a*) the heavy black bones from the silt, and (*b*) some dark-coloured, light-weighted bones, the origin of which was open to suspicion. He urged that it was quite impossible that group 1 could be newer than group 2, but suggested an explanation of the section which would get over the difficulty, namely, that there was an ancient irregular channel excavated in the older *Bison*-gravel, and running north of the boss of London Clay shown in the section, and that in this channel the newer black silt had been laid down. He pointed out that the mollusca were all such as now live in our rivers, two out of the eight being named *fluviatilis* and *amnicum* from that fact. He questioned the possibility of distinguishing a small domestic ox from *B. longifrons* by a fragment of a metatarsal, or a wolf from a dog by one limb-bone, and thought that all the small dark-coloured horn-cores were those of domestic cattle.

Mr. E. T. Newton remarked on the interest attaching to this new discovery of such abundant remains of reindeer in the Thames Valley gravels to the west of London; a species which, as Prof. W. Boyd Dawkins had pointed out, had not been met with in these gravels eastward of London. With regard to the single bone of *Bos longifrons*, he could not accept it as good evidence of the occurrence of that form in the same bed with bison and reindeer, and felt sure that it must have been derived from some newer deposit.

Mr. Lewis Abbott could not help thinking that Mr. Holmes had been very bold in attempting to construct a river some 80 miles long from a single section. The Boulder Clay was coincident with the present valley and occurred at various heights down to about 50 feet on the northern side, and lower still on the southern side: if that did not indicate a valley, he failed to see what would. But why a pre-Thamesian date was claimed for it he could not understand. That the Boulder Clay extended into the Thames Valley, and even over it, was evinced by the large number of Northern fossils and rocks found south of that river. He considered the paper one of great interest and importance.

Referring to Messrs. Leeson and Laffan's paper, he could not agree with the lacustrine origin of the beds under consideration. The list of mollusca commenced with a genus which would almost settle this point: the facies was not lacustrine but sluggish-water, nor was the coarseness of the gravels consistent with a pond or lake origin. The section was, in almost all respects, similar to that exposed at the new Admiralty Offices, where a lateral ridge had existed; upon the hugging of the southern shore by the stream a backwater was left, where a sediment of a more muddy nature was laid down: in this the unique animal-remains were deposited. It was at about the same relative level as that of the Admiralty which produced *Salix polaris*, and was probably of the same age. At the Admiralty section the upper gravels were in all probability much newer than the lower beds, and he ventured to think that also was the case in this instance.

Mr. G. B. Laffan said that most of the bones referred to in the paper had been collected by him personally, and he pointed out on the section the position in which these bones were found. They all came from the bottom of the cutting, either from the dark bed of loam itself, or in close proximity thereto. In the first part of the section no fossils were found, but immediately the dark bed was reached organic remains were discovered in large quantities. For a considerable distance through the cutting they were found, and always at about the same depth from the surface. There was nothing in the circumstances under which they were found to support the suggestion of Prof. Hughes that some, such as the bones of the bison and reindeer, were from a layer different from that whence the others, such as *Bos longifrons*, came. No difference whatever was noticeable in the gravels, and the bones were found in every instance either embedded in the dark layer itself or immediately above it. Several sections have been made in the gravels in the neighbourhood of Twickenham, and the London Clay is usually met with at depths of 15 to 30 feet below the surface of the ground. Organic remains are very rare in the gravels overlying the London Clay. The large quantity of bones, seeds, and shells found in connexion with this dark bed of loam makes the layer one of some interest to geologists, an interest which is increased by a comparison with the dark bed discovered two years ago in Endsleigh Street, described by Dr. Hicks at a previous meeting of this Society, and in which very similar organic remains were found.

Prof. Hull, having seen the sections near Upminster, quite concurred with Mr. Holmes that they showed old Thames Valley gravel resting on Boulder Clay. He wished to refer to the changes in relative levels of this part of England and of the outer sea, indicated by the old river-gravels—both those of Essex and those of Twickenham described by Dr. Leeson. It was probable that these gravels were representative of each other on either side of the Thames Valley, and as the surfaces of the terraces formed by them gradually rose inwards to about 200 feet near Egham and Windsor, they must have been deposited when the land was lower than at present by about this amount. During the process of re-elevation, the river cut back and deepened its channel until the present physical conditions were established.

Dr. Leeson said that the Saiga antelope had been found in the gravels at Twickenham about ½ mile east of the present section, and that these gravels were continuous with those now described. The Saiga was, however, much nearer the surface. With regard to the bone of *Bos longifrons*, about which so much interest had been excited, he could only say that it was brought to him by the same workmen as those who had brought the reindeer and bison, and that the bones were all mixed together in a sack. He saw no reason to question the one occurrence more than the other, and could vouch for the strata in which they are all said to have been found being undisturbed ground.

Mr. T. V. Holmes briefly replied to the remarks made on his paper.

30. *A* Comparison *of the* Permian Breccias *of the* Midlands *with the* Upper Carboniferous Glacial Deposits *of* India *and* Australia. By R. D. Oldham, Esq., F.G.S., Superintendent, Geological Survey of India. (Read June 6th, 1894.)

Contents.

I. Introduction.

In 1855 the late Sir Andrew Ramsay read before this Society a paper [1] on the Permian breccias of Enville and of the Clent, Abberley, and Malvern Hills, in which he gave his reasons for believing that they were deposits of glacial origin. This was followed in 1875 by a paper of the late Mr. H. F. Blanford,[2] in which the suggestion was made [3] that the Talchir boulder-beds of India, whose glacial origin had been recognized in 1856,[4] might have been formed during that glacial period the traces of which had been preserved in the Permian breccias of England.

The glacial origin of these breccias has frequently been disputed, and the doubts cast on them have been to a certain extent reflected on the Indian deposits to which a similar origin has been ascribed. No actual comparison of the two by any observer acquainted with both had, however, been made, and I determined to take an opportunity of visiting some of the exposures with a view of comparing the English and Indian rocks. The opportunity came last Easter, and I have to express my obligations to Mr. Wickham King, F.G.S., who has made a special study of the deposits, and was good enough to guide me to the principal localities and the best exposures.

II. The Permian Breccias of England.

The grounds on which the late Sir Andrew Ramsay based his belief in the glacial origin of the beds were, stated briefly, (1) the distance from which the included fragments came, their source being considered to lie in Shropshire and Montgomeryshire [5]; (2) the large size of some of the included blocks; (3) the presence of smoothed and striated surfaces, like those produced by glaciers, on some of the rock-fragments.

As regards the source of the included fragments, later researches seem to have invalidated the conclusion that they came from a

[1] Quart. Journ. Geol. Soc. vol. xi. pp. 185–205.
[2] *Op. cit.* vol. xxxi. pp. 519–540.
[3] *Ibid.* p. 528.
[4] Mem. Geol. Surv. Ind. vol. i. pt. i. p. 49.
[5] *Op. jam cit.* pp. 191–193.

distance. Mr. Wickham King has for several years been carefully searching the various exposures, and making a collection of the various rocks of which the breccia is composed. His results have in part been published,[1] and a further contribution being in preparation I shall not attempt to deal with this aspect of the deposits.

Leaving this line of investigation, and coming to my own observations, the breccias, wherever they are exposed, are composed of more or less, but never very much waterworn, sub-angular fragments of various sizes; the deposit is always rudely stratified, the various beds generally shading off into each other and not continuing as a rule for any great distance. On Abberley Hill, where the breccia has a coarser grain than any other exposure that I saw, there is a bed of red sand interstratified with the breccia near the upper limit of the quarry, and the material bears evident traces of having been rearranged by running water, but none of having been deposited in a tranquil sea.[2]

A comparison of the various exposures throws some light on the direction of travel of the included fragments. Church Hill is some 6 miles west of Abberley, and is mentioned by Sir A. C. Ramsay [3] as a locality where the stones are unusually angular and broken, and the breccia contains large boulders; since his time, however, a large quarry, opened in this hill, has shown that this is not the case. Not only did we fail to find any block exceeding a cubic foot in bulk, and only a very few at all approaching this size, but there is a very large proportion of sand and fine gravel (less than an inch in diameter); and the smaller fragments are all considerably waterworn, though still imperfectly rounded. At Abberley, on the contrary, there is a very much smaller proportion of fine gravel, and large blocks over a foot across are fairly numerous, the largest block at present to be seen measuring 2′ 7″ × 1′ 5″ × 1′ 5″. On the Clent Hills there is the same contrast between the south and north ends: to the south large blocks are numerous, to the north the rock becomes finer-grained and the constituent fragments more waterworn.

The rock in fact, whether we regard each exposure separately, or the relation of one to another, exhibits all those characteristics which may now be seen in the great gravel-fans that are found everywhere along the foot of the hill-ranges of the drier parts of Western and Central Asia.[4] They form a continuous fringe along the foot of the hills, often extending many miles over the plains; at their upper end they are mostly composed of large fragments, the interstices being filled with small gravel and sand, but farther from the hills the larger fragments are for the most part left behind and the general texture of the deposit is finer. The pebbles, even to the outermost limit, generally remain imperfectly rounded, for when the

[1] 'Midland Naturalist,' vol. xvi. (1893) pp. 25–37.

[2] Two very good photographic views of the breccia are given in Mr. Wickham King's paper, *op. supra cit.*

[3] Quart. Journ. Geol. Soc. vol. xi. (1855) p. 193.

[4] Those of Persia have been described by Dr. W. T. Blanford, F.R.S., Quart. Journ. Geol. Soc. vol. xxix. (1873) pp. 496, 498.

streams flow after rain they are generally so loaded with débris as to be rather of the nature of fluid mud than water, and in this the fragments of rock seem to be carried along *en masse* without being worn against each other to the same extent as in a mountain torrent. The stream, in fact, flowing over a surface of its own formation, has developed such a slope and shape of bed that it is only able to transport its burden, and has little or no surplus energy to devote to the rounding of the rock-fragments. Another effect of the large proportion of mud and stones moved by the streams is that occasional large blocks travel in the moving mass, far beyond where most of their fellows have been left behind; occasional exceptional floods too may bring down larger blocks than usual, which afterwards get covered up by and embedded in gravels of much smaller grain.

To such a cause I would ascribe the deposition of the Permian breccias. That is to say, they were formed by the action of streams, subaerially, and in the immediate proximity of the uplands from which these streams drained. The deposit is too well bedded, and the fragments are often too much waterworn, to be an actual talus, or a landslip formation, extensive as these may sometimes be; it is not sufficiently regularly-bedded to be a marine deposit formed in a tranquil sea, into which fragments of rock were dropped by floating ice; it does not exhibit any of those disturbances of bedding found in the marine boulder-clays of Pleistocene age; and the very local character of the rudely defined strata, the way they pass into each other, combined with the general regularity and parallelism of bedding, seem to preclude the idea that they could have been deposited in a turbulent sea without the agency of floating ice, or formed by a *débâcle*. There remains but the supposition that they were formed subaerially, like the analogous deposits of recent gravel-fans, and in this case the angularity or at most imperfect rounding of the fragments precludes their being of any but local origin.[1]

Though the hypothesis of transport by floating ice must be abandoned as an explanation of these deposits, in favour of a mode of origin little understood when Sir Andrew Ramsay wrote his paper, this in no way affects the question as to whether the striations seen on some of the included fragments were produced by glaciers or not. To this point I devoted some attention, and the results may, perhaps, be not altogether unacceptable.

The locality where striated stones are most abundant, and their mode of occurrence best observable, is the quarry on Abberley Hill. This, and that on Church Hill, are the only two which are cut deep enough to reach the unweathered portion of the deposit. Generally, the quarries only take off the surface-skin of soft and weathered material; on Berrow Hill the quarry cuts a little deeper, and here, as

[1] The same conclusions, regarding the local origin of the materials of which these breccias are composed, have been independently reached by previous observers. See Beete Jukes, 'The South Staffordshire Coalfield,' Mem. Geol. Surv. 2nd ed. (1859), p. 9, and Mr. Wickham King's more detailed researches, as already quoted.

on Woodbury Hill, I found some striated fragments, but neither so abundant or distinct as at Abberley. On the Clent Hills there are no quarries, and the fragments lying on the surface are too weathered to show the finer striæ, if they ever possessed any, while it is impossible to say when or how the coarser ones were produced. Abberley Quarry is consequently the only one where satisfactory observations can be made, and the following remarks must be understood to refer to it and to that portion where the quarry-face exposes the unweathered rock *in situ*. Striated fragments can be found in other places, but some of the points to which importance must be attached cannot be observed.

Fragments showing a certain amount of striation are not uncommon, though by no means universal; the striated fragments did not seem to me more abundant than might be expected in glacial débris, less so, in fact, than in some deposits whose glacial origin is indubitable. The formation, however, consists of fragments of rock of all sizes lying in contact with each other, and as the dip of the beds and the slight deformation of some of the fragments show that they have undergone some disturbance, it might be urged that these striations were produced subsequent to accumulation. There are consequently two separate questions to be considered, namely, whether the striæ were produced before or after the embedding of the fragments on which they were seen; and whether, if they were formed previous to deposition, they were more probably formed by glaciers or by some other agency.

There are some markings to be found which must have been formed by the pressure of adjacent pebbles, such as pittings, not unlike those of the pebbles of the Bunter conglomerate and the Nagelfluh. There are also scratches due to earth-movements subsequent to deposition; but, excluding these, one may also find a fair number of fragments exhibiting a number of parallel scratches, not infrequently crossed obliquely by others, and many of the individual scratches can be distinctly traced for a couple of inches and more. These seem too long to be accounted for by any movements that can have taken place in the body of the rock, for it must be remembered that to produce a number of close-set striæ running across the face of a pebble requires an amount of total movement exceeding many times the length of the individual striæ. I repeatedly searched to see if there were any trace in the body of the rock of shearing-surfaces corresponding to the striated surfaces on the individual fragments, but failed to find them. Further, there did not seem to be any regularity in the direction of the striæ; certainly, where a broad surface of a flat fragment was striated it was generally found more or less parallel with the bedding, but this is what would naturally occur in a stream-deposit. On other fragments the striated surfaces lay at every angle with the bedding, and the directions of the striæ in every azimuth. Moreover, it often happened that only the projections, such as one of the worn-off angles, were striated, while the rest of the stone was unmarked, a feature which is easily explicable if the striation had been anterior to deposition, but would hardly be expected if it had been produced subsequently. For these

reasons it would seem that, with some exceptions, the striation of the fragments was anterior to their deposition, and this conclusion is upheld by an examination of the Church Hill quarry. Here a careful search failed to yield any good specimens of striation, but on a few of the fragments a careful examination revealed some traces, as if of once deeply-marked scratches nearly obliterated. As has already been explained, the Church Hill exposure consists of more waterworn material than the Abberley, and, under these circumstances, it is only natural that striations on the pebbles should be absent, if those at Abberley were produced anterior to deposition; while on the other supposition it is difficult to see why they should not be as common at the one place as at the other. On the Clent Hills the only tolerable exposures I saw were in the finer and more waterworn type of deposit, and here, too, striations were not to be found.

But if the scratches were produced before the fragments on which they are found were deposited in their present situation, the only two agencies that could have been concerned are glaciers or movements of the soil-cap. The soil-cap, either moving gradually down a hillside or when precipitated as a landslip, may certainly produce marks on the subjacent rock which it is difficult, and sometimes impossible, to discriminate from those produced by glaciers, but it is at least doubtful whether it can produce a close and parallel striation of loose fragments such as is seen in many of the fragments at Abberley. The fragments which have retained the striations are all of hard rock, mostly of rhyolite or rhyolitic ash, and these striations can only have been produced by a steady movement accompanied by great pressure; the stone which produced the scratch must, in fact, have been held firmly and pressed hard against the fragment that was scratched, and I am not aware that any case has been observed of loose fragments in a scree or landslip being scratched in the deep and regular manner that is seen on many of the Abberley stones.

Another consideration to be borne in mind is that these effects of soil-cap movements are only locally developed, and that the Abberley rock is certainly not the direct effect of a landslip or talus, but the deposit of a stream. Under such circumstances it is difficult, even if loose fragments could occasionally be scratched by soil-cap movements in the manner these are, to see how they could be so abundant as they are in this quarry; while, if the deposits were composed of rearranged moraine-material, their abundance is by no means too great to be explicable: and this seems, on the whole, to be the most probable explanation of the Abberley deposit and of the very similar deposits on Woodbury and Berrow Hills.

It is only by a consideration of the combination of characters exhibited by a deposit that one can come to a correct conclusion regarding the origin of such a rock as this is. Not a few of the striated fragments I have seen are such as would most unhesitatingly be accepted as truly glacial, if they were found in a recent moraine or in a Pleistocene boulder-clay; many are of a more doubtful character, but not more so than specimens that might be collected out of a boulder-clay of indisputably glacial origin; while it would

be impossible to collect a specimen, even from one of these last-named deposits, for which, taken as an individual specimen and apart from its surroundings, it would not be feasible to suggest some other plausible explanation of origin.

Whether the supposition of the glacial origin of the striated fragments be accepted or not, it will in no way affect the subaerial origin of the breccias and the local origin of their constituents. If it be accepted, the Abberley beds, and those of other localities too, would have to be regarded as deposits analogous to the '*glacial-schotter*' of German geologists: that is to say, as a mixture of moraine and scree-material, transported and deposited by streams.

III. The Indian and Australian Upper Carboniferous Boulder-beds.

I now come to the comparison of the rocks just described with those boulder-beds of Upper Carboniferous age in India and Australia which are regarded as glacial by observers who have studied them in the field. Contrast would, indeed, be a more fitting word than comparison, for I may begin by saying at once that there is not the slightest real resemblance between the two. The English beds consist of a mass of fragments of stone of all sizes, mixed together and resting in contact with each other; the Indian and Australian beds, on the other hand, where typically developed, have always a tolerably, often an extremely fine-grained matrix, itself distinctly stratified, or interstratified with well-bedded rock. Through this are scattered in abundance blocks of rock of all sizes, but always embedded in, and well separated from each other by the matrix.[1] Where this is finely laminated, as is sometimes the case, the bedding may be observed to bend down under and arch over an included fragment, as is seen where a volcanic bomb is embedded in a stratified tuff.

The characters of the rock are, in fact, such as can only be explained by a deposition of the fine-grained matrix in quiet water, into which the large included fragments were dropped from above. The abundance of these is too great to be explained by the action of drift-wood; volcanic agency is excluded by the absence of any contemporaneous volcanic beds; and the only known agency adequate to explain the facts is floating ice. That this is the true explanation is confirmed by the fact that in several places the included fragments show smoothed and striated surfaces exactly similar to those produced by glaciers, and in two localities in India the underlying rock shows the same smoothed, scratched, and *roche-moutonnée* character as is produced by glaciers.

This summary of the characters of the Indian and Australian

[1] A sketch of the Talchir boulder-bed given by C. L. Griesbach, Mem. Geol. Surv. Ind. vol. xv. (1880) pl. ii. fig. 2, shows the character of the deposit very well, and may be contrasted with the photographic views in Mr. Wickham King's paper ('Midland Naturalist,' 1893). The Talchir boulders are by no means universally so well rounded as in Mr. Griesbach's sketch, and in the marine boulder-beds of North-western India the included fragments are generally angular.

Carboniferous beds has been made very brief, as the facts have already been published[1]; but it is sufficient to indicate the grounds on which a glacial origin is ascribed to the beds. It is impossible to bring any hand-specimens which will prove the case, for, as has been remarked, they might individually be ascribed, with greater or less plausibility, to other agencies. The most satisfactory proof, however, lies in the fact that all the observers who have studied these deposits in the field, whatever may have been their prepossessions, have, without exception, come away convinced that ice is the only agent capable of producing the effects which they have seen.

The nature of the Indian beds is so different from that of the English Permian breccias, that it would seem at first sight as if the establishment of the glacial origin of the one has no bearing on the possibility of the presence of glacial débris in the other; and this notion might appear to be confirmed by the fact that the accepted age of the Australian and Indian marine glacial beds and of the Talchir group of the Indian Peninsula is Upper Carboniferous, while the English beds are always called Permian. It must be remembered, however, that the Upper Carboniferous of the former is in reality uppermost Carboniferous, verging on the lower limit of the Permo-Carboniferous of Russia,[2] while the Permian of the latter is lowermost Permian; their age, indeed, is so uncertain that it seems not impossible that they should be regarded as uppermost Carboniferous, and very probably contemporaneous with the Indian beds.

If this be the case, there would be a real connexion between the two, in spite of their apparent differences. We have proof that at the close of the Carboniferous period both India and Australia, apparently also Africa, experienced a period of greater cold than prevailed before or after: a period, in fact, analogous to the Pleistocene Glacial period of the northern hemisphere. This being so, it would not be very extraordinary if the effects were felt in England and allowed of the production of local glaciers, a portion

[1] A complete bibliography of this subject would cover several pages. The chief general accounts are those of H. F. Blanford, Quart Journ. Geol. Soc. vol. xxxi. (1875) pp. 519–540; R. D. Oldham, Journ. As. Soc. Beng. vol. liii. pt. ii. (1884) pp. 187–198; Geol. Mag. 1886, pp. 293–300; and W. Waagen, Jahrb. d. k.-k. geol. Reichsanstalt, Wien, vol. xxxvii. (1887) pp. 143–192.

For India, the original recognition of the glacial origin of the boulder-bed is to be found in the report on the Talchir coalfield by Messrs. W. T. and H. F. Blanford and W. Theobald, Mem. Geol. Surv. Ind. vol. i. (1856) pt. i. pp. 49–51. References to subsequent accounts of these beds and of the more markedly glacial ones of the West and North-west of India will be found in the papers already quoted and in the 'Manual of the Geology of India,' 2nd ed. 1893.

For Australia, see R. D. Oldham, Records Geol. Surv. Ind. vol. xix. (1886) pp. 39–47, and T. W. Edgworth David, Quart. Journ. Geol. Soc. vol. xliii. (1887) pp. 190–195, and the general accounts already referred to.

[2] For India, see W. Waagen, 'Palæont. Indica,' Salt Range Fossils, vol. iv. (1891) pp. 146–156: in the tabular statement opposite p. 238, these beds are placed at the base of the Permian system. For Australia, see R. Etheridge, Proc. Roy. Phys. Soc. Edin. vol. v. (1880) pp. 314–319, and 'Monograph of the Carboniferous and Permo-Carboniferous Invertebrata of New South Wales,' Mem. Geol. Surv. N.S.W., Sydney, 1891, p. 3.

of whose moraine-material was preserved in the so-called Permian breccias of the Midlands.

In this way we come round again to a position not very much removed from that of Mr. H. F. Blanford in 1875,[1] holding that the Permian breccias are the English equivalent of the Indian Talchir group. Whether or not this correlation, or the glacial origin of some of the material of the Permian breccias, be accepted, this much will always remain, that Sir Andrew Ramsay's paper suggested a correlation of the Indian Talchir group which has since been remarkably confirmed by the palæontological evidence.

IV. Conclusion.

Before concluding this paper it may be well to summarize the points contained in it, which are:

(1) That the Permian breccias of the Midlands are subaerially-formed stream-deposits.

(2) That the material of which they were formed, though distinctly waterworn, has not travelled far.

(3) That the striations on the included fragments were, for the most part, produced prior to deposition.

(4) That the striations are of a nature such as requires steady movement under great pressure to account for them.

(5) That the agent to which the production of these striæ can be ascribed with most probability is a glacier.

(6) That the character of the Indian and Australian deposits is such that they can only be ascribed to the agency of floating ice.

(7) That the age of these deposits is probably the same as that of the English so-called 'Permian' breccias.

(8) That the proved existence of a period of exceptional cold in India and Australia makes it less unlikely that glaciers may have existed at the same time in England.

The first six of these are independent of each other, and the acceptance or rejection of one will in no way affect the rest. The last two are more or less interdependent, and are at present as incapable of proof as of disproof.

Discussion.

Prof. Lapworth said that he had listened to Mr. Oldham's paper with especial pleasure, for the subject of the origin of these Permian breccias was one of extreme interest to Midland geologists, some of whom had already made known their general conclusions in various communications at meetings of the British Association and elsewhere. The detailed proofs of their conclusions would, he believed, be given in Mr. King's forthcoming paper, to which Mr. Oldham had alluded.

The Midland geologists had long since found it impossible to uphold the original view of Sir Andrew Ramsay that the

[1] Quart. Journ. Geol. Soc. vol. xxxi.

materials of these Permian breccias had been brought from the Longmynd and Caradoc regions by floating ice. They believed that the facts ascertainable in the field indicated, on the other hand, the general correctness of the view of Phillips and Jukes that these fragments were derived from ancient Midland rock-ridges, subsequently partly removed by erosion, and partly buried up by overlying geological formations. But it had also been discovered that the recognizable materials in the different patches of breccia are so restricted in their local distribution that they do not seem to necessitate the hypothesis of a Permian Glacial period for their formation; and the Midland geologists have been content rather to regard them all as original or rearranged subaerial deposits, like those described by Dr. W. T. Blanford and others as occurring in Central Persia and elsewhere, and to interpret them as phenomena of one of the natural phases in the general Continental conditions indicated by the Permo-Triassic deposits of Britain as a whole. It was very gratifying to learn that Mr. Oldham, who was so familiar with deposits of this character abroad, agreed generally with the Midland geologists in their interpretation of these facts, and as to the probable local origin of the materials of the breccias.

The Midland geologists, however, having relinquished the general theory of the derivation of the materials of the breccias from a distance, and well aware of the fact that some of the patches show evidences of local dislocation, had been afraid to place much reliance upon the evidences of markings and scratches upon the fragments themselves; and Mr. Oldham's paper would do good in calling the very careful attention of local geologists to these curious phenomena. It was by no means impossible that some of the Midland ridges, whence these fragments were derived, were of great height in Permian time, and may, indeed, have nourished small glaciers.

As respects the Lower Gondwana series, which had been paralleled with these Midland deposits, he thought that the original suggestion of Mr. Drew that deposits of such enormous thickness indicated the simultaneous existence of mountain-chains in their immediate neighbourhood, and consequently the existence of local glaciers, was worthy of careful consideration. But it was extremely significant to find that Mr. Oldham, who had personally studied these Permian strata in India and Australia as well as in Britain, was so completely in accord with those who held that they gave evidence of a Permian Glacial period; and he could assure the Author of a hearty reception from Midland geologists, should he find it advisable to continue his researches among the striated stones of the Midland breccias.

The Author, in reply, said that he recognized the existence of scratchings due to earth-movements, but that apart from these there appeared to be others to which this explanation was inapplicable. His principal object had been to point out the great difference between the Permian breccias of the Midlands and the Upper Carboniferous glacial deposits of India and Australia.

31. *On* Deposits *from* Snowdrift, *with* especial Reference *to the* Origin *of the* Loess *and the* Preservation *of* Mammoth-remains.

By Charles Davison, Esq., M.A., F.G.S., of King Edward's High School, Birmingham. (Read June 20th, 1894.)

Contents.

I. Introduction.

The principal object of this paper is to draw attention to the occurrence of deposits from snowdrift, and to describe their nature and the conditions under which they are formed. The subject is a wide one, but in discussing it I have endeavoured to keep constantly in view its bearings on two geological problems, about which there has been, and still is, a considerable difference of opinion. These are the origin of the loess, and the destruction of the mammoth and preservation of its remains. The formation of underground-ice, observed by Dall and others on the northern coasts of America and Asia, will also be referred to.

When snow is driven by a strong wind, it is accompanied under certain conditions by a considerable quantity of dust. The snow and dust are deposited together in sheltered places, and, as the former disappears by melting and evaporation, the dust is left on its surface as a layer of mud, continually increasing in thickness as the snow wastes away. The views here advanced are, briefly, (1) that the loess is such a deposit from snowdrift, chiefly collected when the climate was much colder, but still very slowly growing; and (2) that the mammoth was frozen or suffocated in masses of drift-snow, and subsequently covered by the deposits formed from them, which in certain cases attained a thickness sufficient to prevent further melting of the snow beneath.

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III. Observations on Snowdrift Deposits.

1. Snowdrift Deposits in England.

I will first give a few brief descriptions of deposits from snowdrift observed by myself in this country.

Cambridge: January 18th, 1881.—The area affected by the great storm of this date[1] included the whole of Wales, and all England south of a line joining the mouth of the Mersey to a little north of Flamborough Head. The snow was extremely fine and dry, and penetrated in large quantities through cracks in windows and doors. Its depth was greatest in the South of England, where in places the total fall was as much as 2 feet. The storm was accompanied by an easterly gale of great violence. On one estate alone more than 1500 trees were blown down. Considerable snowdrifts were formed, especially in railway-cuttings, where they occasionally reached a depth of 20 feet. On the Great Western Railway, 51 passenger trains and 13 goods trains were snowed up. At Cambridge the storm, though violent, was less severe. The average depth of snowfall in the district was from 6 to 8 inches, and the drifts were

[1] Symons's Monthly Met. Mag. 1881, pp. 2–24, 42–45.

generally from 3 to 4 feet deep. As the snow melted, it became very dirty, and, when it disappeared, a thick coating of mud was left on the ground, especially where the heaviest drifts had collected. Along a road near Cambridge running N.E. and S.W., the deposit close to the hedge was as much as $\frac{1}{2}$ inch in thickness. It was thinnest in roads whose direction was at right angles to this.

Birmingham: March 1st, 1886.—The storm was most violent in the North of England and in the South of Scotland,[1] but in Birmingham the snow had drifted so thickly that the tram-car service was stopped. For several days previously there had been a hard frost which lasted without intermission during the daytime. On February 28th, the roads were dusty, the interstitial ice in the frozen ground having evaporated. The snow consisted of exceedingly fine ice-needles, which readily found their way through crevices in window-frames. The drifts were from 12 to 18 inches deep, and in places the surface of the snow had a dusky hue. By March 18th most of the snow had disappeared. Nearly all that remained was extremely dirty, and where there was none left the grass was covered with a thin layer of mud about $\frac{1}{8}$ inch thick.

Birmingham: February 19th–20th, 1892.—Snow began to fall a few days before this date, and continued until the 19th. As a rule the temperature was several degrees below freezing-point, and the flakes were nearly always very small. On the ground the snow was fine and powdery, the total depth in spots where it had not drifted being about 2 inches. On February 19th–20th the wind was strong, the snow was raised in clouds, and from the roofs of houses was whirled up in columns and eddies. On the morning of the 21st some rain fell.

In a narrow lane running N.W. and S.E. and a short distance to the south of Birmingham, a good deal of drift-snow had collected. It was banked up against the hedge on the north-eastern side of the road to a height of $2\frac{1}{2}$ or 3 feet, and a breadth of 3 or 4 yards. The surface was, as usual, irregular, and for some distance distinctly dirty or mud-coloured, especially in the hollows of the drift. The snow was slightly dirty for a depth of 4 inches, the finer particles of the mud having been washed down by the rain that fell in the morning, but below this the snow was perfectly clean. Two days later, on February 23rd, the snow was much reduced and dirtier. In many parts the surface was covered with a thin layer of mud, and the whole of the snow down to the ground was discoloured. In one part the dirt lay in streaks at right angles to the road, and these streaks occupied slight depressions in the surface, due probably to more rapid melting. As the snow slowly disappeared, it became granular in texture, and the layer of mud on the surface increased in thickness, especially along edges or angles of hollows in the drift. The ultimate thickness of the deposit was about $\frac{1}{16}$ or $\frac{1}{12}$ inch on an average, but in places it was fully $\frac{1}{8}$ inch. When rubbed between the fingers, the dust felt smooth, almost like flour, though particles of larger size were distinctly visible.

[1] Symons's Monthly Met. Mag. 1886, pp. 17–21, 33–36.

2. Snowdrift Deposits in the Arctic Regions.

In the Arctic regions the conditions are exceptionally favourable for the formation of deposits from snowdrift. The deposits are hardly likely, however, to attract the close attention of travellers, though incidentally the conditions are somewhat fully described in their narratives. One reason, no doubt, for the absence of notices is that, however thick the deposits may be, everything below the first foot or so is perpetually frozen and beyond the range of casual observation. But, just as in this country the last surviving patches of snowdrift are always more or less discoloured, so Arctic travellers sometimes refer to the black and dirty snow to be found in spring at the foot of cliffs. According to M'Clure, decaying ice and snow are of a dingy yellowish hue. Parry remarks that a fall of fresh snow in the summer months gives a more wintry aspect to the scenery than the unmelted snow of the preceding winter. This, he says, is "always easily known by its dingy colour, and its admixture with the soil." The last observation is an important one, and it also explains how snowdrift deposits may be overlooked. The surface of snow- and ice-fields is occasionally darkened by dust, evidently wind-drifted, and dirt-layers are seen in the interior when the edges of tilted floes are exposed or when excavations are made in the snow.[1]

The most direct evidence on this point is that given by the late Dr. J. Rae, who spent several winters in the north of Canada. "In all parts of Arctic America where I have been," he says, "a fall of snow is usually either accompanied or followed by a gale of wind more or less strong, chiefly from one direction, with thick snowdrift, which cuts away earth and sand in minute particles from the windward side of any hill or rising ground in its course, and these particles are carried along until they find a resting-place under the lee of some steep bank or cliff. These foreign substances, when mixed with a great depth of snow, are not readily seen, but when the spring evaporation and thaws remove a great part of the snow, a stratum—more or less thin—of coloured matter, is visible on the surface."[2] It will be seen from the next section that several of the conditions under which snowdrift deposits are formed are clearly described in this passage.

IV. Formation of Snowdrift Deposits.

1. Formation of Snowdrifts.

Snow falls in the form of flakes only when the temperature is not far from the freezing-point. In high latitudes, especially in winter, flakes are unknown, and the snow consists of fine, hard

[1] (The index to the abbreviated references in this and the following footnotes will be found on pp. 472–473.)—Greely, vol. i. pp. 312, 398–99, vol. ii. pp. 30–31; Koldewey, p. 120; M'Clintock, p. 146; M'Clure, pp. 193, 229; Nares, vol. i. pp. 149, 168–69, vol. ii. pp. 12, 59, 61; 'Nature,' vol. xxvii. (March 22nd, 1883) p. 496, vol. xxix. (Dec. 6th, 1883) p. 135; Nordenskiöld, vol. i. p. 178; Parry C, pp. 23, 104, 155.

[2] "Major Greely on Ice," 'Nature,' vol. xxxiii. (Jan. 14th, 1886) pp. 244–45.

ice-needles, so minute that they pass easily through the smallest crevice in doors or windows. At times, countless ice-needles fill the air and make a continual rustling noise; distant objects appear covered with a thick veil or clothed in a dense mist, and the clearness of day is reduced to a dull yellow twilight.[1] But even when the sky seems perfectly clear, these fine crystals hardly ever cease from falling; any object left exposed is soon coated by them, and even the bare patches on hill-tops become gradually whitened by this invisible precipitation.[2]

Fine snow like this lies upon the ground loose as dust or powder, and, until it is closely packed by the wind or encrusted by the action of the sun, it is drifted with the greatest ease. The least puff of wind sets it in motion, and snow-banks are piled up wherever an obstruction is encountered.[3] At Pitlekaj, in Northern Siberia, a shallow, but rapid and uninterrupted stream of snow was observed by Nordenskiöld, and he estimated that the quantity of water thus driven in a frozen form must be equal to "the mass of water in the giant rivers of our globe."[4]

But, important as is the work performed during this incessant drifting, it is not to be compared with that of the violent gales and storms of Arctic lands. There, from the summits of hills and from exposed places, the snow is torn off in sheets by the fierce gusts of wind. In eddying columns it is whirled upwards for hundreds of feet, or driven away in wreaths as if the hill-tops were smoking. Great clouds of snow sweep down the slopes and rush over the cliffs in strange fantastic forms. Down below, on the more level ground, the whole air is filled with flying, streaming snow, which no human being can face, and none can endure for many hours. Objects a few yards off are completely hidden from view, and soon every landmark is obliterated.[5] Such storms may last for days, and when they are spent the crests of the hills are seen to be bared, the valleys and ravines are choked with light soft snow, and under the shelter of cliffs there collect great snow-slopes which often outlast the succeeding summer.[6]

[1] Belcher, vol. i. pp. 318, 358; De Long, vol. i. pp. 147–48; Greely, vol. i. p. 183; Hayes, p. 194; Koldewey, p. 422; Markham, p. 161; Nares, vol. i. p. 319; Nordenskiöld, vol. i. p. 517; Parry *C*, p. 77; Payer, vol. ii. pp. 50, 61; Richardson, vol. ii. p. 98.

[2] Hayes, p. 218; Nares, vol. i. pp. 246–47; Parry *B*, pp. 153, 420; Parry *C*, p. 77; Payer, vol. i. pp. 244, 299, 300.

[3] Belcher, vol. ii. p. 85; Nares, vol. i. p. 146; Nordenskiöld, vol. i. p. 473; Parry *B*, pp. 129, 139, 189, 200.

[4] Nordenskiöld, vol. i. pp. 483–84; Andrée, pp. 523–33.

[5] De Long, vol. i. pp. 147–48, 258, 343; Gilder, pp. 118–19, 164–66; Hayes, pp. 189–91, 302; Koldewey, pp. 125, 383–84, 399, 422; Lansdell, vol. ii. pp 563, 635; M'Clintock, pp. 60, 95; M'Clure, pp. 237–38; Markham, pp. 161, 169–70; Nares, vol. i. pp. 142, 163; 'Nature,' vol. xi. (Feb. 25th, 1875) p. 334; Nordenskiöld, vol. i. p. 483; Parry *A*, pp. 109–10, 156–57, 179; Parry *B*, pp. 150, 190; Wrangell, p. 194.

[6] For references to snow-slopes under cliffs, see Beechey, vol. i., pl. facing p. 311; Belcher, vol. i. p. 272 (also pl. facing p. 271); Greely, vol. i. p. 312; Nares, vol. i. pp. 241, 286, 290, 316, vol. ii. pp. 79, 90–92; 'Nature,' vol. xxiii. (Jan. 14th, 1886) p. 244; Richardson, vol. i. pp. 279, 283–84.

The amount of snow that settles in valleys and ravines, especially in those whose direction is at right angles to that of the prevailing wind, must be very considerable. I have not succeeded in finding any reliable estimates. The common expression that after a storm the ravines are filled with drift-snow cannot be taken to mean much. At the foot of a mountain in Grinnell Land, Greely met with a line of almost vertical snow-banks and drifts, the front of which ranged from 100 to 150 feet in height.[1] This is probably an unusual amount, and it may have been the accumulation of many seasons. But if we remember that 10 or 15 feet is not an excessive depth to collect in railway-cuttings during one of our severer English storms, and then compare the latter with the far more violent and more frequent Arctic gales, we shall be prepared to accept a high estimate. On the other hand, the total snowfall in Arctic regions is by no means great, but the snow is much denser than that which falls in warmer climates. The average weight of a cubic foot of snow at Port Bowen was found by Rowland to be 30 pounds.[2]

The time of year at which snowdrifting is most frequent and considerable is a subject on which information is still required.[3] In Russia, where snowdrifts seriously disturb the railway-system, Mr. Sresnewskij has made some interesting enquiries. He finds that the drifting is at a maximum in mid-winter, but there is more in the second half of winter than in the first, there being then more snow to drift. There are also most drifts in the months when the snowfall is least and in which there are fewest days of snow.[4]

2. Origin and Transportal of the Dust.

In Arctic countries, hills and exposed places are soon denuded of their snow, a few hours being sufficient for a strong wind to remove the fall of many days. Even when the snow has become so packed as to provide blocks for snow-buildings, it can in these situations offer no permanent resistance to a violent wind. Plains are sometimes cleared so that sledging is impossible.[5] It is from such places bared of snow that the material of snowdrift deposits is derived. The hard frozen ground may be converted into dust in two ways: (1) by evaporation of the interstitial ice, and (2), as

[1] Greely, vol. i. pp. 402-3; Nares, vol. i. pp. 323-24. As snow in large masses is granulated at a small depth, may not extensive accumulations of drift-snow be sometimes confused with snow-covered glaciers? On this point see Hooker, vol. ii. pp. 90, 116; Nares, vol. ii. pp. 17-18, 79-80.

[2] Parry *C*, p. 77, footnote.

[3] It can hardly be determined from the casual records in Arctic narratives, for the drifts would naturally attract more attention in the sledging season.

[4] 'Nature,' vol. xliv. (Aug. 20th, 1891) p. 389.

[5] Belcher, vol. i. pp. 156, 161, 238, 318; Greely, vol. i. p. 183; Lansdell, vol. i. p. 228 (footnote); M'Clintock, pp. 210-11; Markham, pp. 153-54; Nares, vol. i. pp. 163-64, 188; Parry *A*, p. 169; Ross, pp. 171, 177, 208, 618; Wrangell, pp. 36, 276.

Dr. Rae suggests, by the friction of hard particles of wind-driven snow. Of these, the first is probably by far the more efficient.

Dust due to Evaporation of Interstitial Ice.—Evaporation takes place from ice and snow at the lowest temperatures experienced in high latitudes. "When a shirt, after being washed," says Richardson, "is exposed in the open air to a temperature of 40° or 50° below zero, it is instantly rigidly frozen. . . . . In an hour or two, however, or nearly as quickly as it would do if exposed to the sun in the moist climate of England, it dries and becomes limber." The joints in houses built of ice-blocks are gradually enlarged by evaporation, so that drift-snow can enter; and a freely-suspended cube of ice, according to Payer, lost one-hundredth of its weight daily from the same cause during the latter half of March.[1] It is important to notice that the evaporation occurs without any apparent wetting of the surface on which the snow or ice has been resting[2]; so that, when the interstitial ice of frozen soil evaporates, the surface is left dry and dusty. In England I have frequently noticed that the roads become dusty after a few days of dry frosty weather[3]; and the same phenomenon has been observed by Sir G. Nares, but to a far greater extent, in lat. 82° 26′ N. "Along the borders of the old lake-bottoms," he remarks (on May 7th, 1876), "the mud, which was frozen as hard as any rock during the winter, is now pulverized; where a month ago it was difficult to dig out stones and shells with a metal instrument, a stick or the finger can now easily be forced an inch deep into the softened earth; this must be entirely due to evaporation." And again (Aug. 13th) he writes:— "At this season the ground was evidently hardening for the winter. During the spring, long before the temperature of the air was above freezing-point, the earth became pulverized to the depth of two or three inches, all the moisture which had rendered it hard throughout the winter having evaporated. During the latter part of the summer the moisture again collects as dew and the earth hardens completely."[4] While dust must be formed in this way, though in small quantity, all through the winter, it will be noticed that it is greatest in amount at a time of year when snowdrifting is of frequent occurrence.

Dust due to Friction of Hard Particles of Wind-driven Snow.— At very low temperatures the fine grains of snow become intensely hard. If rubbed upon the face in cases of frost-bite, they cut through the skin. Sledges no longer glide, but drag heavily as if over a surface of sand or sandstone, unless the runners are wet and so coated with a thin layer of ice. When driven by the wind these hard particles act as a sand-blast, wearing down blocks of snow and ice; and, in a passage already quoted, Rae states that

[1] Hayes, pp. 218–19; Nordenskiöld, vol. i. p. 509; Payer, vol. i. pp. 244, 258, 276, vol. ii p. 114; Richardson, vol. ii. p. 100.

[2] Hooker, vol. i. p. 245; Nares, vol. i. pp. 272, 276, 311–12, 318.

[3] I may add that I have never observed any deposits from snowdrift when the weather preceding the fall of snow was comparatively mild and damp.

[4] Nares, vol. i. pp. 315–16, vol. ii. pp. 134–35.

they cut away earth and sand in minute particles from the windward side of any hill or rising ground in their course.[1]

Transportal of the Dust.—In whichever way the dust is derived, it will be driven with or after the snow and deposited in the same places, either mixed with or covering the drifts. That it should ever be noticed in the act of drifting with the snow is improbable, considering its extreme fineness. Nares records, however, "a blinding snowdrift mixed with sand and small pebbles which were carried by the fury of the storm." Snow and sand are sometimes driven in the faces of travellers as they walk, so that they can scarcely keep their eyes open. During his journey along the Lower Aniuj River, in North Siberia, von Matuischkin made a similar observation. "The death-like stillness which prevailed," he says, was "suddenly broken by violent gusts of wind, howling and sweeping through the ravines, and whirling up high columns of snow and sand."[2]

Long after all the snow has been blown away from exposed places dust may continue to be conveyed by the wind to the surface of snowdrifts. "In consequence of the bareness of the land from snow," Nares remarks on Sept. 19th, 1875, "the dust has been carried off by the wind, and has discoloured all the floebergs. This evidently accounts for the dust sediment left at the bottom of the water pools on the surface of the floes, and for that frozen deeply into the ice" (vol. i. p. 149). Nor are dust-storms unknown in Arctic regions, one that occurred on July 9th, 1882,[3] being recorded by Greely. It is evident that some of the dust transported in this way may ultimately form a part of deposits from snowdrift.

3. Hardening of Snowdrifts.

So long as the snow remains loose and powdery on the surface, snow-banks accumulated on open ground are continually shifting like sand-dunes, and drifts in many places are liable to removal with a change of wind.[4] Under these conditions, deposits from snowdrift would not have a much greater prospect of preservation than any ordinary, unprotected, æolian formation, unless they occur in very sheltered valleys and ravines. Generally, however, the snow, by superficial melting and re-freezing, is soon encrusted with a layer of ice, or it is closely packed by the action of the wind. The dust is thus imprisoned in the hardened snow, and the deposit from it tends to become a permanent addition to the products of former years.

Snow hardened by the Action of the Sun.—Long before the temperature of the air reaches the freezing-point, the sun has sufficient

[1] De Long, vol. i. pp. 299–367, vol. ii. p. 517; Greely, vol. i. pp. 211, 224; Hayes, p. 285; M'Clintock, pp. 210–11; 'Nature,' vol. xxxiii. (Jan. 14th, 1886) pp. 244–45; Nordenskiöld, vol. ii. p. 103; Payer, vol. i. p. 254, vol. ii. pp. 11, 52–53, 114; Wrangell, pp. 102–3, 104.

[2] Koldewey, p. 422; Markham, p. 154; Nares, vol. i. p. 142; Wrangell, p. 194.

[3] Greely, vol. i. p. 410.

[4] Nares, vol. i. pp. 273–74.

power at mid-day to affect the snow. The surface is thus made soft and sticky, and, during the frost which follows, every crystal receives a thin coating of ice and the snow becomes granular in texture, the optical axes of the grains being of course disposed in every possible direction. As the grains increase in size, the intervening air-spaces are more or less filled up, and the surface of the snow is glazed and soon coated with a crust of ice. In the Lower Kolyma district (Siberia) this state of the snow, according to Wrangell, is called 'Nast.' "The hunters profit by it to pursue the elks and reindeers by night; and as the weight of these animals causes them to break through, they fall an easy prey."[1] Thaw-water from the surface, however, continues to filter through the capillary passages in the crust, and, meeting with the colder snow below, is again frozen, the whole mass thus becoming granular. "Early in the spring," says Nares, "wherever the stratification of the snow covering a floe had become exposed at a newly-formed crack, the lower portion of the snow was observed to have granulated, the grains collecting together perpendicularly, the lower ones being the largest and leaving intermediate air-spaces." According to observations made by Parr during Markham's northern sledge-journey in 1876, "the general depth of the snow was from two and a half to three feet, the upper portion, underneath the surface crust, consisting of loose grains of about the size of rifle fine-grain powder, and without the least coherency; these gradually increased in size, till about two thirds of the way down they were as large as rifle large-grain powder, but still separate. Below this, however, the grains began to unite and to form very porous ice, till, at the actual point of junction with the floe, it was very difficult to draw the line of demarcation. In all cases the ice on the surface of the floes had evidently been formed in the same manner, for it was full of air-holes, though not nearly to so great an extent as that which was in process of formation. . . . In one case, also, we found a section of a drift seven feet thick at the highest point, which was divided into three equal parts by two layers of ice half an inch thick; the lower portion being nearly converted into ice, the middle not to such an extent, while the upper had only just commenced."[2] If, then, the melting take place slowly, masses of snow are in time converted into ice identical, except perhaps in the absence of marked fluxion-structure, with that formed in glaciers.[3]

Snow hardened by the Action of the Wind.—As already remarked, snow at low temperatures is dry and loose. In ravines and under cliffs, where the snow is sheltered from the wind, it remains in this condition, until the sun has power to glaze or melt it. But if exposed

[1] Wrangell, p. 61 (footnote).
[2] Nares, vol. ii. pp. 63–64, 69.
[3] Andrée, p. 524; Nares, vol. i. pp. 279, 301, 367–68; Nordenskiöld, vol. i. pp. 136–37; Parry *B*, p. 114; Richardson, vol. ii. pp. 99–100; Ross, pp. 163, 510; Scoresby, vol. i. p. 34; Wrangell, p. 61 (footnote); Whymper, pp. 426–31. See also an admirable paper by F. A. Forel, 'Le Grain du Glacier,' Arch. des Sc. phys. et nat., vol. vii. (1882) pp. 329–375.

to the wind it is packed and hardened, and until this happens snow cannot be used for building, and sledging is difficult and often impossible. "Fortunately for the architects," says Nares, "the gales in the middle of September had formed hard snow-banks, out of which a compact building-material was readily procured." "The snow, in spite of the low temperature," says Payer (Oct. 25th, 1872), "lay in such masses between the small hummocks and on the few level places that they [the sledges] sank deep into it. It is storms of wind only that harden the snow, and for some time we have had calms or light breezes." "Yesterday's storm," remarks Greely (Jan. 17th, 1882), "has stripped every exposed place of its usual snow, to pack it in dense, hard drifts, in the hollows of the ground."[1] So far as I am aware, no explanation has been given of the action of the wind in hardening snow at a low temperature; but that it has such an effect is clear from numerous observations, and from the importance attached to it by Arctic travellers.

4. Disappearance of Snow by Melting and Evaporation.

During the Arctic winter snow and ice undergo but little decay, for evaporation then takes place slowly, and it is not until late in the spring that the sun can effectually melt the snow. The sun alone has but little thawing power, until it has attained a considerable altitude. It is aided greatly, however, by the presence in the snow of dust, sand, and minute plants, and when the dark earth or rock below becomes partially uncovered, or when the snowdrift deposit begins to appear on the surface, the rate of decay is materially hastened. Showers of rain, and dry warm winds of a *föhn*-like nature, also assist largely in the disappearance of snow.[2]

Isolated stones and small patches of earth, owing to their power of absorbing heat, sink some distance into snow; kryokonite, as is well known, is found at the bottom of holes in the Greenland ice. But a thin and continuous coating of earth, like that which covers many decaying snowdrifts, practically remains upon the surface, though the finer particles may be washed down by rain and thaw-water, to discolour the snow-granules below. So long as it remains thin, this coating helps to melt the subjacent snow, and it increases in thickness by the continual addition of particles to its under-surface. But a limit may at last be reached, depending chiefly on the depth to which the summer-heat penetrates the ground, when the deposit on the surface becomes thick enough to prevent further melting of the snow until a warmer climate supervenes.

[1] Greely, vol. i. pp. 183, 224; Hayes, pp. 217–18; Koldewey, pp. 376–77; M'Clintock, pp. 207, 391; Markham, p. 344; Nares, vol. i. pp. 177, 190–91, 222, 292; Payer, vol. i. pp. 178–79, 229, vol. ii. p. 39; Richardson, vol. i. p. 349.

[2] Belcher, vol. i. p. 312; Hooker, vol. i. p. 252; Markham, pp. 380–83; Nares, vol. i. pp. 40, 310–11, vol. ii. pp. 3, 6–7; Nordenskiöld, vol. ii. pp. 33–35; Parry *A*, pp. 165–66, 176; Parry *B*, p. 114; Payer, vol. ii. p. 252; Seebohm, p. 101.

V. Nature of Snowdrift Deposits.

1. Fineness of Texture.

One of the most noticeable features about the snowdrift deposits that I have had an opportunity of examining is their extremely fine texture. When rubbed between the fingers, the material generally feels smooth like flour. If it be put in water and disturbed, part sinks within a few minutes, but the water remains discoloured for several days. No doubt a strong wind is capable of driving, and does drive much larger particles; instances have already been given of sand drifted with snow. But such particles would not be carried far; they would be easily dropped during brief lulls in the storm, and perhaps dropped beyond recovery. The finer dust, however, remains suspended in air for some time and may be carried great distances. Extensive and continuous deposits from snowdrift must almost inevitably be fine-grained.

2. General Absence of Stratification.

When the decay of snowdrifts takes place slowly, it seems almost evident that the deposits from them must be unstratified. For, as each granule of snow melts, the fine dust-grains coating it subside irregularly, and there is no force acting, as in currents of water, to arrange them in any definite direction. Occasionally dust of larger size from a nearer origin might be deposited in a snowdrift, or dust of an entirely different nature, and these might form layers in the future deposit. They might even give it an appearance of stratification, the layers being roughly parallel to the original surface of the ground. But the snow in a drift lies so irregularly and is of such varying depth, the rate at which it decays depends so much on the thickness of its coating of mud, and in this mud there may be differential movements as it is gradually lowered by the decaying of the snow below, that the probability of any final appearance of stratification is rather remote. If continuous layers were, however, formed, they would most likely be of a wavy and irregular character.

In connexion with this absence of stratification, I made several experiments during the winter of 1891–92, one of which may now be described. On a large piece of millboard, I placed (1) a layer of clean snow, 25 inches long, 17 inches broad, and 6 inches thick; (2) above this a layer of snow mixed with fine dry soil, the snow and soil being showered alternately until a layer 3 inches thick of dirty snow was formed; (3) on this a layer of clean snow 5 inches thick; (4) a layer, 11 inches thick, similar to the second, except that the dust was previously mixed with mica-flakes, most of them very small; and (5) a top-covering of clean snow, 3 inches thick. The appearance of the mound was carefully watched from day to day. The uppermost layer of snow soon melted, and the usual

covering of mud was formed on the surface. After 18 days the snow had entirely disappeared, and a deposit nearly an inch thick was left behind. In this there was not the least sign to be detected of any surface of separation between the mud from the second and that from the fourth layers. The only trace of their original division was the presence of the mica-flakes in the upper part of the deposit.

This experiment is, I think, of some value, though not perhaps decisive—on account of the small scale on which it was made. To prove the general absence of stratification in snowdrift deposits, I would rather trust to the absence of any reason why stratification should exist.

Arrangement of Mica-flakes in Snowdrift Deposits.—In the Chinese loess, Richthofen has observed that mica-flakes are arranged indiscriminately and not horizontally, and it was on this account that mica-flakes were mixed with the dust in the fourth layer of the preceding experiment. The flakes were generally small, most of them about $\frac{1}{100}$ inch or slightly more in diameter, but some were larger, and a few were about $\frac{1}{4}$ inch long. While the snow was melting, these flakes appeared in the mud extruded on the surface, but there was no sign whatever of a horizontal disposition. When the snow had completely disappeared, from the largest flake to the smallest they were inclined at all angles to the horizon, and in every direction.

Occasional Stratification in Snowdrift Deposits.—Pools of thaw-water are sometimes formed on the surface of decaying snow; streams of melted snow may carry into them some of the surface-mud, and true aqueous deposits may thus be intercalated in the snowdrift formation. These pools are no doubt caused in some cases by the varying thickness of the incipient snowdrift deposit. "Round a ship which has wintered in the ice," says Payer, "there is gradually accumulated a mass of rubbish of all kinds, of which cinders form a considerable constituent. These, when thrown out in small quantities, sink at once into the snow, while larger quantities act as a non-conducting layer. Hence we were surrounded by a maze of holes, big and little, alternating with plateaux, under which winter still continued to linger. When thaw-water made its appearance, all this was transformed into a succession of lakes and islands, which we bridged over by planks." [1]

During rapid thaws, the water rushes down valleys and ravines in torrents, and mud and gravel are spread out in sheets over the snow and ice at their mouths.[2]

But in both these cases, unless the deposits are laid down directly on snowdrift formations having no thick layers of snow and ice beneath them, the original stratification must be largely interfered with by differential movements due to unequally rapid melting of the snow below.

[1] Payer, vol. i. p. 251.
[2] Nares, vol. ii. pp. 12, 55–56, 65–66; Scoresby, vol. i. p. 476.

VI. The Origin of the Loess.

I propose now to refer as briefly as possible to the geological problems mentioned at the beginning of this paper.

The snowdrift theory of the loess is in great part described in the preceding pages. During the Glacial period a large part of Europe was unoccupied by ice. In the districts adjoining the ice-sheet, a similar though milder climate must have prevailed. The winters must have been long and the summers comparatively short; the former being characterized by heavy storms, violent gales, and much snowdrifting. Abundant dust-material would be provided by the products of glacial erosion. During the summer most of the snow, except in sheltered places, would melt, and the snowdrift deposits would be formed chiefly in the valleys, more thinly on the higher ground and plateaux. Thus, every year a new layer would be added, each layer merging imperceptibly into that of the previous season, the whole covering high and low ground alike, except that it would attain a greater thickness in the more sheltered places, and would be altogether absent in exposed spots on hillsides and crests. With the advent of a warmer climate and the retreat of the ice-sheet, there would be a gradual expansion of the snowdrift formation, overlapping the glacial deposits along their border, but diminishing in thickness the more rapidly the ice withdrew.

In many respects the snowdrift theory bears a close resemblance to the æolian theory of Baron F. von Richthofen. But they obviously differ in some important points. I will now endeavour to show, (i) that the snowdrift theory accounts for the more prominent features of the loess, and (ii) that it escapes several of the objections which have been urged so forcibly against the æolian theory.

The snowdrift theory seems to me to give a satisfactory explanation of the following peculiarities of the loess, which distinguish it so strongly from the other formations with which we are acquainted: (1) its independence of altitude above the sea-level; (2) its occurrence in uniform sheets over plains and table-lands, and the concavity of its surface when developed between two ridges; (3) its homogeneous composition and structure; (4) the complete absence of stratification in *pure* loess, and the indiscriminate arrangement of included mica-flakes; (5) the occurrence of *angular* grains of quartz; (6) the inclusion of layers of angular fragments in loess near hillsides; (7) the great quantity of bones of mammals (this will be referred to in the next section); (8) the presence of land-shells and the preservation of delicate shells; and (9) the peculiar character of the fauna, resembling that of sub-Arctic steppes or tundras.

I have not referred here to the calcareous concretions, the root-like tubular structure, or the tendency to vertical cleavage, all characteristic features of the loess. The concretions are in all probability a subsequent formation, and do not here require a special notice. The explanation of the others given by Richthofen, if it holds for the æolian theory, will also probably hold for the snowdrift theory.

In the particulars mentioned above, the two theories agree very closely. The first five points and the eighth are explained equally well by both; but in the remainder the balance, I think, inclines slightly in favour of the snowdrift theory.

I will now mention a few points in which the snowdrift theory seems to me to have a decided advantage, in explaining objections which it is more or less difficult to meet on the æolian theory. (1) It accounts more satisfactorily for the fixing of the dust-material: first in snowdrifts hardened or packed by the action of sun and wind, and afterwards in the frozen ground. (2) It agrees with the geographical distribution of the loess, its occurrence as a fringe—a partly overlapping fringe—to the glacial deposits. (3) It postulates no change of climate or geographical conditions other than those which nearly all are agreed did obtain during the Glacial period; and it does not require the existence of a central desiccated area.

Lastly, the snowdrift theory gives an explanation of other related pheuomena, namely, the destruction of the mammoth and the preservation of its remains, and the origin of the underground-ice formation. In this it fulfils one of the most stringent tests of a satisfactory theory.

VII. The Preservation of Mammoth-remains.

Several writers have advanced the view that the mammoth met with its fate during violent storms accompanied by intense cold and blinding snowdrifts.[1] In order to escape the violence of the storm, animals would rush to the nearest woods (if they existed) or to any sheltered place, the very spots where snowdrifts, owing to the cessation of the wind, would be most thickly collected. In these drifts they would frequently be snowed up, or entrapped in their efforts to escape when the storm was over. As the snow gradually disappeared, the deposit from it would envelop the mammoths, and thus their remains, if the climate continued cold, would be embedded in frozen earth, containing perhaps layers of granular snow as hard and firm as glacier-ice.

The abundance of remains in particular spots may be due partly to the mammoths continually seeking the same places of shelter, but chiefly, I think, to the earth being the comparatively thin residual deposit from the masses of snow in which they were entombed.

VIII. Origin of the Underground-Ice Formation.

The underground-ice formation, consisting of alternate layers of ice and clay, has been described by Dall and other writers. Allusions to layers of ice in the ground are also met with in the narratives of several travellers.[2]

[1] Strong wind with snowdrift produces a feeling of suffocation, which is not experienced in wind without snowdrift; see Koldewey, p. 399.

[2] W. H. Dall, pp. 104–111; W. H. Dall & G. D. Harris, pp. 260–68, with references to other observations; in addition to which see Lieut. Kendal, p. 64;

In high latitudes, masses of drift-snow under favourable conditions occasionally last through the summer. The deposit formed on the surface by their partial decay serves as an additional protection,[1] the snow that remains having been rendered granular by the re-freezing of infiltrated thaw-water, and perhaps slightly discoloured by the fine particles of dust carried down by it. If the same process is repeated year after year, a mass of ice will be formed, the growths of successive seasons being separated by thin layers of earth or clay. But, in all probability, this will not often occur, and a year of abundant snowdrifting may be followed by others in which the snow disappears more or less completely, and the annual deposits practically coalesce. Now, in Arctic regions, the summer thaw does not often penetrate beyond about a foot in depth.[2] If, then, the thickness of the deposit should ever exceed this limit, it follows that the snow below will not melt so long as the climate remains unchanged. In this way, alternate layers of ice and clay may be built up, the ice corresponding to the snow of a few unusually heavy drifts, the clay being the residual deposit from several or many slighter ones. The remains of animals should thus occur chiefly in the layers of clay; but, if the theory be correct, they should be found sometimes, though perhaps rarely, in the layers of ice.

Discussion.

Prof. Blake asked what necessary connexion snow had with the formation of loess. As far as he could see, the dust could be blown about as well without it as with it, and the deposit might equally well be formed in a tropical climate to-day as during the Glacial period.

Prof. Boyd Dawkins considered that the word 'loess' was an unfortunate term. If the material were called 'loam,' it would at once be realized that loam may be either the result of the wind or of deposit by water, or the work of the earthworm. The mammoth had nothing to do with the question, because it occurred in the South of Europe and in North America far away from the range of the 'loess.'

Mr. Oldham said that he happened to have a personal acquaintance with the deposits left after the melting of snow and with the loess. The former were found in sheltered spots on the ridges of the Himalayas which are annually covered with snow, but (so far as his experience went) they were denser and more compact than the true loess; they were in fact dried muds, while the true loess was a dust. On the hills of the Western frontier of India, where loess was largely developed and still in course of formation, the distribution, surface-contour, and constitution showed it to be a wind-

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M'Clintock, p. 146; Nares, vol. ii. pp. 12, 13, 47, 66; Nordenskiöld, vol. i. pp. 378, 436 (footnote), vol. ii. p. 204; Parry *C*, p. 23; Wrangell, pp. ciii, cxxxi–cxxxii, 50–51, 222–24, 279.

[1] Nares, vol. ii. p. 66; Nordenskiöld, vol. ii. p. 61; Payer, vol. i. pp. 184–85, 251; Ross, p. 618.

[2] Nares, vol. ii. p. 77; Parry *B*, p. 124; Wrangell, pp. lii, 38–39, 185, 276.

blown dust deposit, though it passed into deposits which had been re-arranged by water. Part of this lay at altitudes where snow fell each year, but it was equally well and typically developed below the level at which snow usually fell, and where it was not preceded by a long frost nor lasted long enough to form extensive drifts. He did not think that the true loess could originate from the solid matter left by melting snow, and it could certainly be formed without the aid of snow.

Dr. W. F. Hume observed that the views as to loess which still held the field were three:—

1. The diluvial theory, accounting for it as due to flood-waters set in motion by volcanic action. This view appeared to be untenable, if the total absence of volcanic evidence in the main areas where loess was present were taken into account.

2. The origin of the European loess as the result of the melting of large glaciers, having been either originally deposited in lakes or as fluviatile loam. This view was strongly held by many Russian geologists, æolian action being almost entirely ignored.

3. Æolian action the prime factor, as maintained by Baron Ferd. von Richthofen, though glacial action might have played a considerable part in originating one type of this deposit. Some deposits, as in Australia and India, would appear to be entirely due to this action.

The suggestion made by Mr. Davison would be a subsidiary aspect of theory No. 2.

The President drew attention to an important paper published in the 'Geological Magazine' for 1889 on the Origin of the Loess ('Subaërial Deposits of the Arid Region of North America,' by Israel C. Russell, of the U.S. Geol. Survey, Washington, D.C., U.S.A., Geol. Mag. dec. iii. vol. vi. pp. 289–295 & 342–350), showing how a large portion of that deposit may have originated by fine sediments deposited subaqueously in great, shallow, inland lakes. The lakes having become desiccated, these sediments have subsequently been removed and re-deposited by æolian action as unstratified loess.

32. *On* DEEP BORINGS *at* CULFORD *and* WINKFIELD, *with* NOTES *on those at* WARE *and* CHESHUNT.

By W. WHITAKER, B.A., F.R.S., F.G.S., Assoc. Inst. C.E., and A. J. JUKES-BROWNE, B.A., F.G.S.[1]

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CONTENTS.

I. INTRODUCTORY.

A BORING at Culford having unexpectedly given evidence of the underground rise of older rocks in Suffolk, a county in which there was no such evidence before, we thought that it should be described before this Society. Another boring, in the parish of Winkfield, having also proved the presence of Lower Greensand deep underground in Berkshire, by the southern border of the Valley of the Thames, it occurred to us that it might be noticed at the same time, as bearing on the same general question, namely, the underground extension of beds.

Much delay has occurred in the writing of the descriptions of these sections, but this is the less to be regretted as it has enabled us to add a great deal of detailed information concerning the boring at Ware, and some also on that at Cheshunt. In the case of Ware, indeed, no details have hitherto been published—only a mere abstract of the section, and that not accurate in the Cretaceous divisions.

In none of these cases could we print our notes in a Geological Survey Memoir, all these notes being supplementary to Memoirs already published; but we trust that no excuse is needed for again

[1] [It is but right to say that, though my name comes first, by disadvantage of seniority, my colleague has had the larger share of the work in this paper.—W. W.]

bringing before the Society a subject of so much interest as that of the older rocks underground in the South-East of England, in connexion with which we venture to say that it is of some importance to get accurate knowledge of the beds above the old rocks.

We desire to acknowledge the great assistance that we have received from our friend Mr. W. Hill, who has made some forty microscope-slides from the rocks found in these borings, sending us descriptive notes and critical remarks on all of them. These notes and opinions are embodied in our paper. We have also to thank Mr. J. Francis, the Engineer of the New River Company, and Messrs. Le Grand and Sutcliff, for the information and the specimens upon which the paper is based.

[Since this paper was sent in to the Society Prof. Dawkins has made an important addition to the literature of the great Dover boring, in which he gives details of the Cretaceous and Jurassic beds.[1] It is often a difficult matter to classify beds from specimens brought up from great depths, and we are disposed to question some of the classifications in this case, though we hesitate to express an opinion without seeing specimens. We should expect the section of the Cretaceous beds below the Gault, at the site of the boring, to differ somewhat from that in the cliffs south-westward, to which the author refers, especially as a great difference seems to be shown by another deep boring at Dover, already described by one of us.[2]

By some oversight the author has noted the Jurassic beds as occurring only at two of the deep borings in or near London (Richmond and Meux's), whereas they have also been found, more lately, at Streatham, the boring at which place has escaped notice in his table.

We have thought it best to take this opportunity of noticing these points, rather than to wait for the more convenient season which depends so much on seeing a large set of specimens, and which may be postponed to the good time that is often so long in coming.]

II. The Culford Boring.

General Account of the Work.

The site of this boring is just outside the northern edge of Culford Park, about $\frac{1}{8}$ mile S.E. of Rats Hall and 5 miles N.N.W. of Bury St. Edmunds: the height of the ground being about 110 feet above Ordnance datum.

The boring was commenced in 1890, and finished in 1891. Its diameter is at the top 6 inches, and the boring is lined with 5-inch pipes down to a depth of 583 feet.

It was undertaken for the purpose of obtaining a supply of soft

[1] Trans. Manchester Geol. Soc. vol. xxii. pt. xvi. (1894) pp. 488–510.
[2] Quart. Journ. Geol. Soc. vol. xlii. (1886) pp. 35, 36, and vol. xliii. (1887) pp. 199–203.

water for some new buildings on the Earl of Cadogan's estate, and it was expected by the engineers (Messrs. Le Grand and Sutcliff) that such a supply would be found in the Lower Greensand, as in the neighbourhood of Cambridge. They were advised by Mr. W. H. Dalton, who calculated that the base of the Gault would be reached at about 610 feet from the surface, a prediction which proved to be within about 5 feet of the truth.

The hope of getting water, however, was not realized: a plentiful supply of hard water was found in the Chalk, but the sandy beds below the Gault did not yield any water. The Gault seems to pass down into sandy clay, below which are alternations of calcareous stone and sandy material, and at the depth of 637½ feet the bore entered a hard greenish slate.

Puzzled by this hard rock, and finding that Mr. Dalton was away from home, Messrs. Le Grand and Sutcliff applied to the Geological Survey Office for information, sending samples from the lowest part of the bore. On examining these we reported that Palæozoic rocks had been reached, and that the prospect of obtaining water by going deeper was very small. At the same time we pointed out the importance of the discovery of Palæozoic rock at so small a depth, and urged Messrs. Le Grand and Sutcliff to obtain Lord Cadogan's permission to carry the boring a little deeper—in order to ascertain, if possible, to what formation the slaty rocks belonged. The boring was carried nearly 20 feet deeper, through soft slaty shale with some harder beds, and was stopped in this material at a depth of 657¼ feet.

The following is the account of the boring sent to us by Messrs. Le Grand and Sutcliff, and we prefer to give this first, exactly as furnished by them. We will then describe the samples which were submitted to us, and by their aid will endeavour to determine the stratigraphic horizons of the beds. Unfortunately the samples obtained were too few to enable us to do this in a very satisfactory manner.

	Thickness. Feet	Depth. Feet
Pit (dug)	6	6
Chalk and flints	341	347
Hard chalk and flints	26	373
Chalk-rock [*i. e.* very hard chalk] with a layer of flints at the base. Sample 1	16	389
Hard chalk with a layer of flints at the base. Samples 2 & 3	18	407
Hard chalk	7	414
Soft chalk	4	418
Chalk, rather hard. Sample 4	59	477
Chalk getting like marl	6	483
Grey chalk-marl. Sample 5	79	562
Gault, dark-grey clay. Samples 6, 7, & 8	36	598
Sandy Gault. Sample 9	27	625
Sandy Gault and stone in alternating layers. Samples 10, 11	11	636
Greensand stone. Sample 12	1½	637½
Claystone. Sample 13	2½	640
Shaly stone. Sample 14	17¼	657¼

Description of Samples.

1. Rather hard, yellowish, marly chalk, very like the material which occurs in the marl below the Melbourn Rock at Whittington, near Stoke Ferry in Norfolk.

2. Compact and rather hard, homogeneous, white chalk. Under the microscope it shows a fine amorphous matrix in which are numerous single calcareous cells, many of which are empty. It most resembles slides of Upper Chalk.

3. A flint, black throughout, without any white rind or envelope.

4. Very soft, pulverulent chalk, and in its dry state almost pure white. It is either one of the softest beds of the Chalk Marl, or part of a mashed-up core, probably the latter.

5. Light grey marl: effervesces freely, but is nevertheless decidedly argillaceous. Mr. W. Hill cut a piece of this and reports that its structure closely resembles the marly Upper Gault of Norfolk; in his opinion it is Gault. There was no note of the exact depth from which the sample was taken.

6. Dark grey marl, evidently a Gault marl, but it effervesces freely with hydrochloric acid.

7. Phosphatic nodules and fossils, including *Belemnites attenuatus*, *Nucula pectinata*, fish-vertebræ, and part of a gasteropod.

8. Dark grey clay, effervesces slightly.

9. Dark-grey, sandy clay. An extra sample from 600 feet is a dark clay, with larger grains of sand.

10. Very soft, wet, sandy clay; when washed this is found to consist of very fine mud enclosing a quantity of sand, the grains of which vary much in size; the greater part—perhaps two thirds—of the sandy material is clear white quartz, partly in rounded partly in angular grains. The residue consists chiefly of small water-worn fragments of grey slate or argillite, closely resembling material occurring in the Palæozoic rocks below. There are also a few grains that seem to be glauconite. Probably the bed from which this sample was obtained is really a somewhat dirty or silty sand, the fine mud which now binds it into a sandy clay having been derived from the Gault above and mixed with it in the process of boring.

11. Several samples. A greyish-brown stone, from 632 feet, containing many small brown bodies looking like decomposed oolitic grains of iron; a grey gritty-feeling stone; a piece of lignite, embedded in brown ferruginous sandstone containing large grains of yellow and brown quartz; lastly a fragment of an ammonite.

Both these grey stones are calcareous, and when sliced and examined under the microscope are seen to be limestones of a very peculiar type. They consist mainly of shell-fragments set in a matrix of shell-dust, cemented by calcite; a few grains of quartz are seen, but the grittiness of the rock is evidently due to the shell-fragments, as in the case of the Totternhoe Stone. Most of these fragments are pieces of echinoderm-shell, some are molluscan, and there are a few foraminifera (chiefly *Textularia*). The brown

particles in the greyish-brown stone are not oolitic, but seem to be merely organic fragments stained by oxide of iron; many are friable and break away in the preparation of the slice, leaving empty spaces with a ferruginous lining, but others remain and seem to be rolled pieces of shell partially replaced by a yellow-brown mineral, presumably a decomposed glauconite. Others are stained black by what may be manganese (it is not cubical pyrites). The grey stone has less matrix and a greater number of organic fragments, some rolled and some angular: besides echinoderm and molluscan shell a piece of *Terebratula*-shell and a lattice-work fragment (? coral) can be seen in the slide, which is traversed by a vein of calcite. There are also some oval bodies which in shape resemble cypridcases.

12. A light-grey calcareous rock, bearing so close a resemblance to the grey stone above described that it might be from the same bed. Dr. Hinde, to whom a slice was sent, remarks that "it seems to be mainly composed of plates and spines of echinoderms, probably sea-urchins, fragments of molluscan and entomostracan shell, a few foraminifera, and an occasional sponge-spicule, but I do not recognize coral-structure in it. The foraminifera are principally *Textularia*, but there are specimens of another genus with perforated walls." A few grains of quartz are scattered through the slide.

Mr. Hill remarks to us that the general assemblage of organic fragments and their arrangement is similar to that in some of the raised coral-reef rock of Barbados.[1]

13. A hard, light greenish-grey, slaty rock, showing what seem to be two sets of cleavage-planes: one of these slopes at an angle of about 60°; the other forms jagged edges on the broken surface of the block, and seems to be nearly parallel to the vertical face of the core. The block was said to come from 638 feet.

14. One from 647 feet is a mash-up of soft, grey, shaly rock enclosing fragments of hard slate or argillite. Another from 650 feet is a dark-grey compact rock with white veins: this looked like a limestone, but did not effervesce with acid and appears to be a kind of hornstone or argillite with quartzose veins. A third sample from 657 feet is a dark-grey slaty rock resembling some of the imperfect slates or killas of Devon and Cornwall, but it might equally well be of Cambrian or Ordovician age.

Slides from several samples of these slaty rocks were made at the Geological Survey Office, and were examined by Mr. Teall. One, marked as coming from between 645 and 647 feet, is a fine-grained siliceous stone of the lydianite or hornstone type and is traversed by numerous white quartz-veins. Mr. Teall describes it as composed of minute crystals of quartz, felspar, white mica, brown mica, and chlorite, the first two minerals predominating.

Another, labelled as "shale 657 feet," he describes as composed of exceedingly fine particles—amongst which a few grains of quartz and scales of mica may be recognized.

[1] See Quart. Journ. Geol. Soc. vol. xlvii. (1891) p. 244, and pl. ix. fig. 4.

Slides were also made from the greenish slate, in view of the possibility of its containing minute organic remains, but though these slides were examined by Mr. Teall, by Messrs. Sharman and Newton, as well as by ourselves, not the slightest trace of any organic structure has been detected.

Classification of the Beds.

The conclusions to be drawn from the above description seem to be as follows:—

(i) If the sample from between 373 and 389 feet is from the base of the Melbourn Rock, the beds below 389 feet belong to the Lower Chalk. Samples 2 and 3 must in this case have been taken from chalk and flints which fell down the bore. No sample of Totternhoe Stone or of the sandy base of the Chalk Marl has been preserved.

(ii) Only one sample in 79 feet of strata between the depths of 483 and 562 feet has been kept, and this proves to be Gault. We are therefore without evidence as to the base of the Chalk, but if the thicknesses of Lower Chalk and of Gault are similar to those near Burwell and Soham, west of Culford, there would be about 150 feet of the former and 90 of the latter, or 240 feet altogether. Now, assuming that the Lower Chalk in the boring begins at 389 feet and that the Gault ends at 625 feet, these two formations are 236 feet thick, which is a very close correspondence.

There is, however, some little doubt as to the base of the Gault, for the sample from 600 feet had grains of coarse sand such as generally occur only in the lowest 5 or 6 feet of the Gault, and it may be therefore that the actual base of that division is very little below 600 feet; the rest of what is termed "sandy Gault" being similar to that in the underlying beds described as "sandy Gault and stone."

As the Gault is likely to be somewhat thinner towards the east, we do not suppose that more than 30 out of the 79 feet called "grey chalk-marl" is really Gault. If this inference be correct, the Lower Chalk at Culford is 143 feet thick, its base occurring at the depth of 532 feet; while if the base of the Gault be taken at 605 feet, this division would have a thickness of 73 feet.

With respect to the beds between 625 and 636 feet, the brown sandstone enclosing lignite has the aspect of ordinary quartzose Lower Greensand, but the calcareous beds do not resemble any part of that group exposed in Cambridgeshire or Norfolk. These limestones were in fact so different from any rock previously known to us that we were long in doubt about their age, and the possibility of their being Jurassic had occurred to us; but on referring to Prof. Judd's account of the rocks below the Gault at Richmond [1] we recognized a certain similarity of structure. On mentioning this to Prof. Judd he very kindly lent us some of the slides which

[1] Quart. Journ. Geol. Soc. vol. xl. (1884) p. 738.

had been prepared from the Richmond samples, and on examining these we found that the Culford limestones bore a very close resemblance to the highest part of the Richmond series, *i. e.* the top part of that classed as Neocomian by Prof. Judd.

Not only is the general structure similar, but the same varieties of stone occur: thus one sample from Richmond, at 1141½ feet, is a grey stone without any brown grains, but consisting of broken shell-fragments (echinoid and molluscan), with some cyprid-cases, a few foraminifera, and a few scattered grains of quartz, embedded in a dull calcareous matrix. This is similar to the grey limestones of Culford. Another slide (marked from 1141½, but probably a little lower than the first) and one from 1144 feet show similar enclosures, but the fragments are more rolled and scattered, many are stained by a dark brown material, some partially and some completely, and the matrix is clear crystalline calcite. These resemble the rock with brown grains at Culford, in which, however, the matrix is dirtier and the fragments rather smaller. Both have very little quartz, and cannot be called sandy rocks.

Such close resemblances in structure between two rocks occupying the same stratigraphic position are certainly suggestive of identity in age, especially as we know of no other rock which has a similar structure.

Of the uppermost portion of this limestone at Richmond Prof. Judd remarks that "the rock very closely resembles, both macroscopically and microscopically, certain varieties of the Kentish Rag." It is true that the calcareous sandstones which occur in the Hythe Beds between Hythe and Sevenoaks, and are known as Kentish Rag, vary considerably in microscopic structure; but, so far as we can judge from the slides that we have examined, they seldom consist very largely of shell-fragments. Sometimes they contain much quartz and glauconite, sometimes very little. At Hythe the prevalent kind of limestone seems to be one containing a large number of sponge-spicules, with a few shell-fragments, a fair amount of green glauconite, and comparatively little quartz. Except in the small amount of quartz, this will not compare with the Culford rock.

There is, however, much resemblance between the finer-grained stone at Culford and a calcareous stone in the Hythe Beds at Tilburstow Hill, near Godstone. There is a specimen of this in the Museum of Practical Geology (Case E, 2076), and a slide was cut from it for our inspection. The matrix is crystalline granular calcite, and through this are scattered shell-fragments, sponge-spicules, glauconite-grains and a few quartz-grains, both of these being small. A few of the shell-fragments show echinodermal structure, and there are several foraminifera, including a *Textularia*.

We have also compared the Richmond and Culford rocks with three slides of Bargate Stone from localities near Godalming and Guildford, and find a considerable degree of resemblance between them. These samples of Bargate Stone consist mainly of shell-fragments, among which bits of echinoid shell and spines are abundant, set in a matrix of clear crystalline calcite; the amount of quartz

and glauconite varies greatly, one slide having no visible quartz and another very little quartz and no grains of glauconite, while in the third both are in fair quantity.

From these observations and comparisons we think ourselves justified in concluding that the Culford and Richmond limestones are of the same age, and that they belong to the same group of rocks as the Kentish Rag and the Bargate Stone; that is to say, to what is usually termed Lower Greensand, the beds which one of us proposes to call Vectian, but for which Prof. Judd prefers the name Neocomian.

The fragment of an ammonite was submitted to Messrs. Sharman and Newton, who report that it is unlike any known Cretaceous species, and most resembles *Ammonites Valdani* of the Lower Lias; at the same time, they say that the fragment is too small to be identified with certainty, and that it might belong to some other Jurassic species. It would appear, therefore, to be a derived fragment, like those so frequently met with in the Lower Greensand, and, as such, is useless for determining the age of the beds in which it was found.

So far as we can ascertain, no pebble-bed occurs at the base of the Cretaceous series at Culford: the account given being that the boring-tool passed directly from the lowest calcareous stone into the greenish claystone or slate.

With respect to the Palæozoic rocks, of which nearly 20 feet were pierced in the boring, we are unfortunately able to say very little. Those who have seen them differ greatly in opinion as to their age. Mr. W. H. Dalton sees resemblances to the Wenlock Shales, and would refer them to the Silurian system. He informs us that he judged chiefly from a sample of soft shale containing "a bit of limestone resembling that of Upper Silurian." As stated on p. 492, we found this to be not a calcareous, but a siliceous rock. Dr. J. E. Taylor writes that the softer shaly slate is like the shales found at Harwich, and considers both to be of Lower Carboniferous age. For ourselves we think there is nothing distinctive about them, and that such shales and slates might occur in any cleaved area of Carboniferous, Devonian, Ordovician, or Cambrian rocks; but we do not think they resemble the Upper Silurian rocks of Shropshire, and that is the type of Silurian which occurs below Ware. There is only one point on which all are agreed, namely, that these Culford slates are older than the Coal-Measures. The angle and direction of dip could not be ascertained.

So far, therefore, as the samples preserved enable us to form an opinion, the age and thickness of the several formations passed through are as follows:—

	Thickness. Feet.	Depth. Feet.
Pit (? in Drift)	6	6
Upper and Middle Chalk	383	389
Lower Chalk	143	532
Upper Gault	30	562
Lower Gault	43	605
Vectian (Lower Greensand)	32½	637½
Palæozoic rocks	19¾	657¼

As already stated, it is possible that the base of the Gault may be as low as 625 feet, in which case the Vectian is only $12\frac{1}{2}$ feet thick, but we are disposed to think the above is the most probable interpretation, and in this Mr. Dalton agrees with us.

III. The Winkfield Boring.

General Remarks.

In May, 1893, a deep boring was finished at New Lodge, the house of M. Van de Weyer, in the parish of Winkfield (but only about 100 yards from the border with Bray), and over $3\frac{1}{2}$ miles nearly W.S.W. of Windsor Castle. This site is in the London Clay tract of the district known as Windsor Forest, from which the work has to some extent become known as the Windsor boring, a title to which it has no right.

During the progress of the boring we have been in frequent communication with Messrs. Le Grand and Sutcliff, who made it. To them we are indebted for a detailed section of the beds passed through, and for various specimens. In this case also Mr. Dalton was consulted by the well-sinkers.

The site, at the southern border of the grounds, about 150 yards from the house, and about 130 westward from Nobbscrook Farm, is 218 feet above Ordnance datum, the above measurements being made not on the ground, but from an Ordnance map (Berkshire, Sheet 31) on which the site had been marked by Messrs. Le Grand and Sutcliff.

A small pit was dug, to the depth of only 8 feet, when the boring was begun, and with the intention of going no deeper than 250 to 350 feet. Consequently, provision was made only for a pipe 5 inches in diameter to be carried down 231 feet, or 17 feet into the Chalk. It can readily be imagined, therefore, that great difficulties had to be encountered, and that many expedients were resorted to in order to take the boring more than 1000 feet deeper than the point to which the pipes reached: indeed the engineers say, in a letter, that, "hampered at every step, the marvel to us now is that we ever reached the Lower Greensand," to get water from which was the object of going so deep.

It is for its success in this that the boring is notable, such success being rare in very deep borings—putting aside such a case as Caterham, close to the outcrop of the Lower Greensand, and various wells in the Valley of the Medway, where a large amount of water is got by borings through the Chalk and the Gault into the sand beneath. Of deeper borings at sites in the London Clay tract of the London Basin only two others have succeeded in getting water from the Lower Greensand. One of these is at Loughton in Essex, where water was found at the base of the Gault, and presumably therefore from Lower Greensand, at the depth of 1096 feet; whilst in the other, in Kent at Chattenden, northward of Chatham, this formation was entered at the depth of 1162 feet. The boring now described is therefore the deepest as far as Lower Greensand is concerned, including the case of Richmond, where the formation occurred at the depth of 1140 to 1150 feet.

Details of the Section.

		Thickness. Ft.	In.	Depth. Ft.	In.
[London Clay.]	Brown clay	6	0	6	0
	Blue clay	54	0	60	0
	Black [flint] pebbles	1	0	61	0
	Blue clay and clay-stones [septaria].	54	0	115	0
	Brown dead [clayey] sand [? basement-bed]	15	0	130	0
	Green sand, shells and water [basement-bed]	6	0	136	0
[Reading Beds, 78 feet.]	Mottled clay	14	0	150	0
	Very hard yellow clay	14	0	164	0
	Brown sand, with water	11	0	175	0
	Mottled clay and sand	17	0	192	0
	Light[-coloured] blowing sand	22	0	214	0
Upper Chalk, 329 feet. Solid masses of flint, several feet thick, in part.	Chalk and flints	79	0	293	0
	" " sticky	30	0	323	0
	" " hard	159	0	482	0
	" " sticky	21	0	503	0
	" " " and brown	32	6	535	6
	Black chalk	7	6	543	0
[? Chalk Rock.]	Hard grey chalk and flints	8	0	551	0
Middle Chalk, 169 feet.	Hard white chalk	13	6	564	6
	Grey sticky chalk and flints	2	6	567	0
	" " a flint at 578 feet.	15	0	582	0
	(Another account says hard white chalk, 20 feet.)				
	White sticky chalk	8	0	590	0
	White chalk	27	0	617	0
	Grey sticky chalk	6	0	623	0
	Hard white chalk	25	0	648	0
	Hard, sticky, white chalk	2	0	650	0
	Hard chalk	29	6	679	6
	Hard white chalk	14	6	694	0
	Grey gritty chalk	4	0	698	0
	Chalk marl	4	0	702	0
	Hard white chalk	4	0	706	0
	Very hard white chalk [? Melbourn Rock]	14	0	720	0
[Lower Chalk, 219 feet.]	White and green chalk [? *Belemnitella* Marl]	6	0	726	0
	White chalk	27	0	753	0
	Hard white chalk	44	0	797	0
	Free-cutting white chalk	12	0	809	0
	Hard white chalk	15	0	824	0
	Very hard white chalk	7	9	831	9
	Very hard grey chalk	17	1	848	10
	Hard dark-grey chalk [? Totternhoe Stone]	18	2	867	0
[Chalk Marl, 72 feet.]	Blue clayey chalk. Specimen with minute flakes of mica and some black specks	1	0	868	0
	Dark-brown clayey chalk	21	0	889	0
	Grey chalk, with hard bands from 1 to 13 inches thick. Specimen from 927 ft.: like the hard beds of the Chalk Marl (with 'spheres,' Hill). Specimen from the base: dark grey marl, with quartz-grains, mica-flakes, and black particles [? glauconite]: small bits of glauconitic marl	50	0	939	0

		Thickness. Ft. In.	Depth. Ft. In.
UPPER GREENSAND.	Some resembling the Upper Greensand at the Wallingford and Moulsford borings. Specimen from 939 ft. 8 in.: dark-grey plastic Chalk Marl with many glauconite-grains, enclosing bits of a harder or drier, more glauconitic marl. After treatment with acid and washing, a bit left about two thirds of its bulk, consisting almost wholly of quartz and glauconite. Probably Chalk Marl has been carried down by the boring-tool into the sand. Specimen from 942 ft. 8 in.: hard grey marl full of grains of quartz and of glauconite. Specimen from 956 feet: calcareous malmstone, having a matrix of granular calcite, with many angular bits of calcitic shell, many sponge-spicules and minute scattered grains of quartz and of glauconite. This slide also shows a great number of black specks (pyrites?) which fill chambers of very small foraminifera (*Textularia* and others). Specimen from 956 ft. 8 in.: hard, compact, grey stone, sandy, micaceous, fine-grained. Specimen from 960 feet: hard, compact, grey sandy stone, with some calcareous matter. Specimen from 968–970 feet: fine-grained sandy stone like the last, but with little calcareous matter	31 0	970 0
[GAULT, 264 feet.]	Gault [clay]. Became dark and sticky at 994 feet (sample brought up dry). Specimen from 1006 feet like Lower Gault (W. Hill). Hard, dry, friable [light-grey] clay at 1050 to 1056 feet. Then dark soft clay [grey, with some bits of a lighter colour], impeding the progress of the pipes. *Ammonites splendens* at 1170 feet, when the clay becomes harder. *Inoceramus sulcatus* at 1170 and 1179 feet (E. T. Newton). Phosphatic nodules from 1171 feet	260 0	1230 0
	Brown and dark-greenish sandy clay. Sand only observed near the base. At the base a layer of phosphatic nodules	4 0	1234 0
LOWER GREENSAND.	Fine, sharp, light-brown sand, of the ordinary character of that in the Folkestone Beds. With water	9 0	1243 0

Remarks on the Geological Divisions.

The basement-bed of the *London Clay* being well marked, so also is the amount of that formation and the thickness of the *Reading Beds*. The latter agrees with what is shown by various other well-sections in the neighbourhood, in which the thickness of this formation varies from about 70 to over 90 feet, except for Slough, where it falls to a much lower figure.[1]

There is some doubt as to the position of the *Chalk Rock*, and it may be that it is the bed below that suggested which ought to be so classed. Of course, therefore, the division between the *Upper* and the *Middle Chalk* is somewhat doubtful.

[1] See Geol. Surv. Mem. 1889, 'The Geology of London and of Part of the Thames Valley,' vol. ii. pp. 3–10, 334, 335.

The *Lower Chalk* is rather thick, and the whole formation of the *Chalk* is about 80 feet thicker than under London and 55 feet thicker than at Richmond. So clayey are some of the specimens from the *Chalk Marl* that we were at first inclined to think, as also was Mr. W. Hill, that the Gault might have been reached, and therefore that the Upper Greensand was absent—a view that was of course negatived when the last-named formation was found to occur still lower. A specimen from 927 feet was submitted to Mr. W. Brierley (of Southampton), who reports that it is composed of 62·1 per cent. of calcium carbonate, with a small quantity of iron, etc., and 37·9 per cent. of clayey matter—a composition not varying much from that of some highly calcareous Gault.

The *Upper Greensand* seems to have been reached at about 939 feet, when the boring entered a sandy marl: this may be from 6 to 10 feet thick, and is underlain by impure malmstone. A specimen of the latter, from 956 feet, is sandy and has the same structure as a calcareous malmstone from Selborne, a slide of which was lent by Dr. Hinde. Each contains about the same amount of quartz, in very minute grains: that from Selborne, however, having rather more glauconite and more foraminifera, but rather fewer spicules and hardly any black specks. A calcareous malmstone from Reigate, a slide of which was also lent by Dr. Hinde, has much more glauconite than either of the above and more sponge-spicules.

The *Gault* is very thick, being from 63 to 133 feet thicker than in the deep borings in and around London, the nearest approach, anywhere in the London district, being at Shoreham in Kent (38 feet less), and the only excess being at Caterham, by nearly 80 feet.

From a geological point of view, it is of course to be regretted that the boring was not carried deeper, to prove the thickness of the *Lower Greensand* and to find by what this formation is underlain. We may perhaps venture to suggest that it is not likely that Wealden beds would be found, but that any division of the great Jurassic series may be represented, and that probably some Jurassic formation would be passed through before the older rocks are reached.

Notes on the Water.

The level of the water from the Chalk was 151 feet down, or only 67 feet above Ordnance datum. In September 1890 the supply was weak, and at the end of November pumping, at the rate of 3 gallons a minute, lowered the water from this source 32 feet. This poor yield from the Chalk is what might be expected from a bore of small diameter carried through more than 200 feet of Tertiary beds, but it does not prove that the Chalk here is practically waterless.

On May 9th, 1893, at the end of the work, the water from the Lower Greensand rose to over $2\frac{1}{2}$ feet above the ground. This water-level steadily rose, as the borehole was shelled out, and reached the height of 7 feet 8 inches, or more than $225\frac{1}{2}$ feet above Ordnance datum, on May 18th.

The high level to which the water from the Lower Greensand

rises is owing to the height of the outcrops of that formation, and probably also to the somewhat free passage of water through it, as well as to the fact that the source has now been tapped for the first time in the district. In the case of the Chalk, on the other hand, the nearest outcrop is at the level of the Thames, and a large quantity of water is taken by various wells. One can hardly expect, however, that the high level of the water from the Lower Greensand will be maintained, but rather that it will fall slightly after some time, especially if other successful borings be made.

[In a communication to this Society, made a short time ago and not published until after this paper had been sent in,[1] Prof. Hull gave it as his opinion that the water came from the southern outcrop of the Lower Greensand rather than from the northern one. In this we agree, as the former is broad and unbroken, whereas the latter is narrower and broken. We do not, however, see with him (as one of us said at the time) that there is any evidence that the southern outcrop is divided from the northern one, near Windsor, by the uprise of older rocks (as shown in the section which he exhibited). It may be so; but, on the other hand, it may not. There may be continuity here, though there is discontinuity under London; and at present we are without evidence, knowing only that water-bearing Lower Greensand is present.

The woodcut from this section has been altered to show the continuity of the Gault over the ridge of old rocks, in deference to remarks made in the discussion on the paper.[2] While thanking the author for this courteous acknowledgment, we must be allowed to differ from him in the opinion that "the question is one which is entirely conjectural"; for of the many borings in the London Basin that have been carried deep enough, every one has proved the presence of Gault, and in one only, at Harwich, has it been found to be thin.]

The following chemical analysis of the water from this boring is not without geological interest, for in containing a comparatively large amount of common salt it follows the rule of many other deep well-waters, both from Cretaceous and from Jurassic beds. The difference between the analyses of water, from wells sunk through a good thickness of Tertiary beds into the Chalk and from wells in which the Chalk is at or near the surface, has been commented on by one of us,[3] who, however, had not at the time read a paper by Mr. R. Warington, in which much light is thrown on the subject.[4] It seems as if the salts once held in the higher outcropping parts of a permeable formation had been gradually dissolved out by the long-continued passage of water down and through them, such salts being then carried in the water to lower parts, whereas in those parts where the beds are saturated and from which the water cannot escape the contained salts are retained.

[1] Quart. Journ. Geol. Soc. vol. l. pp. 152–155 (May 1894).
[2] *Ibid.* p. 154.
[3] Geol. Surv. Mem. 1889, 'The Geology of London and of Part of the Thames Valley,' vol. i. pp. 514–516, 533 and table opp.
[4] Journ. Chem. Soc. vol. li. (1887) pp. 544, 545.

ANALYSIS of a sample of water received from Messrs. Le Grand and Sutcliff, 27th May 1893, from New Lodge, Windsor Forest, at the depth of 1243 feet, by Dr. B. DYER.

		Grains.
Total dissolved matter		61·74
Loss on incineration of residue		·84
Chlorine in chlorides (equal to chloride of sodium 43·37).		26·32
Free (actual or saline) ammonia		·045
Albuminoid (organic) ammonia		·003
Oxygen, absorbed by oxidizable organic matter, etc., from a solution of permanganate of potash at a temperature of 80° Fahr.	In 15 minutes.	·003
" "	In 4 hours ..	·011
Phosphoric acid		traces

No nitrogen in nitrates.

Hardness before boiling 3°, after boiling 0°.

Appearance in two-feet tube turbid. Microscopic examination satisfactory.

The dissolved matter consisted of the following (in grains):—

Carbonate of lime	2·24	61·74
Carbonate of magnesia	·73	
Carbonate of soda	4·99	
Sulphate of soda	9·17	
Chloride of sodium	43·37	
Oxide of iron and alumina	·28	
Silica, traces of organic matter, etc.	·96	

"So far as regards organic matter this water is remarkably pure, as would be expected from the depth. The most remarkable feature about it is the presence of a large quantity of common salt. This of course is not prejudicial to health, though persons of delicate palate might detect a faint trace of salt. The hardness is only 3 degrees, so that for laundry purposes the water would be economical. It would also be excellent for boiler purposes, in the sense that it would not form a crust; though a steam-boiler, of course, would want occasional blowing-out—owing to the concentration of salt."

IV. THE WARE BORING.

History of the Work.

The site of this boring is on the alluvial flat of the River Lea, between the Hertford Branch Railway and the stream from Chadwell Spring, and ¼ mile N.E. of that spring. It is marked by the word "Well" on the Ordnance map (Hertfordshire, Sheet 29). The level of the surface is about 110 feet above Ordnance datum. The work was undertaken by the New River Company (who have given the name Broadmead to this Pumping Station), partly for the purpose of obtaining a larger water-supply from the Chalk, and partly with the object of ascertaining whether water-bearing Lower Greensand could be found below the Gault.

The work was begun in 1877, and the Gault was pierced early in 1879, Palæozoic rocks being found below it at a depth of 796½ feet.

A core of the Palæozoic rock was examined by Mr. Etheridge, who found that it was full of Wenlock fossils, and he accordingly announced the existence of Upper Silurian Beds below Ware in a letter to the 'Times' dated May 16th, 1879.

A brief account of the boring was subsequently given by Mr. Jas. Barrow,[1] who assigned the following thicknesses to the several formations, but gave little geological information about them :—

Shaft 34 feet; the rest bored.

		Feet.
Surface-earth, gravel, and sand		14
Chalk	Soft Chalk	416
	Chalk Marl	128
Upper Greensand		77
Gault		160
Lower Greensand		1½
Wenlock Shale, dipping 40° southward		35
		831½

In 1880 Mr. Hopkinson published a paper 'On the Recent Discovery of Silurian Rocks in Hertfordshire,'[2] but he did not discuss the other formations.

Mr. Etheridge adopted and reprinted Mr. Barrow's account of the section in his Presidential Address to the Geological Society for 1881.[3] He added some further particulars about the Palæozoic rocks, but did not give any description of the Cretaceous rocks, nor did he state the grounds on which thicknesses were assigned to the Chalk Marl and Upper Greensand respectively. He repeatedly mentions the occurrence of 18 inches of "Lower Greensand of the Carstone type" below the Gault, but he gives no evidence for the identification of any particular sample as 'Carstone,' and we cannot accept this statement as proof of the existence of Lower Greensand. To this point we shall recur in the sequel.

No fuller account of the rocks traversed by this boring has ever been published. The importance of the discovery of Silurian rocks seems to have so dwarfed all interest in the Cretaceous beds, that no careful examination of them was made at the time. Had Ware come within the scope of any Geological Survey memoir that was in hand after the boring had been made, one of us would probably have hunted for further information, as in the case of the Cheshunt (Turnford) boring, of which a fairly full account has been printed (see p. 508).

Fortunately the New River Company kept a set of specimens from both borings, and their Engineer, Mr. J. Francis, having kindly sent us portions of these, we are now able to give some details and to correct the short statements already published about the boring at Ware—statements which one of us has reproduced, though with some doubts.[4]

[1] Proc. S. Wales Inst. Engineers, vol. xi. no. 7 (1879), p. 322, pls. 50, 51.
[2] Trans. Watford Nat. Hist. Soc. vol. ii. pt. 7 (1880), p. 241, pl. ii.
[3] Quart. Journ. Geol. Soc. vol. xxxvii. (1881) *Proc.* p. 230.
[4] Trans. Herts. Nat. Hist. Soc. vol. iii. pt. 5 (1885), p. 179.

Having examined the samples sent us from the Ware boring we selected 20, about which it seemed probable that the microscope would reveal more exact information. These were sent to our friend Mr. W. Hill, who has been good enough to slice and examine them, and to furnish us with a written account of the minute structure of each slide.

When a sufficient number of samples have been preserved from the strata traversed by a boring, we think that they deserve a more careful and detailed description than specimens obtained from a quarry, because the section is not open to observation and yet may be far more extensive and important than any quarry-section. We propose, therefore, to give a general description of all the specimens sent us by Mr. Francis, inserting Mr. Hill's notes on those specially examined by him.

Description of Samples.

The figures represent the depth in feet from the surface from which the sample was taken, but Mr. Francis informs us that many were cut off cores of more than a foot in length, and consequently the depth assigned may not be exact, though near enough for all practical purposes.

116. Soft white chalk. Under the microscope shows a fine amorphous matrix with a fair number of small shell-fragments. Resembles chalk from the zone of *Micraster cor-testudinarium*.

145 & 149. Soft white chalk; that from 149 has a thin streak of grey marl. It was sliced by Mr. Hill, who describes it as consisting mainly of fine amorphous material in which can be seen a fair number of thin-shelled spheres, some foraminiferal cells, and many minute *Textulariæ*, with a few small shelly fragments. The marly part contains a greater number of larger shell-fragments, arranged with their longer axes in one direction, as if by current action.

160, 172. Soft white chalk. 172 consists chiefly of amorphous material, with many spheres and some small shell-fragments.

174, 178. Firm, rather tough chalk, with wavy grey streaks of marly material.

211, 212. Rather hard white chalk. Of 211 Mr. Hill says:—"A good specimen of Middle Chalk; spheres are fairly abundant, the majority thin-shelled; a few large *Globigerinæ* occur; shell-fragments are few and small."

231, 246. Soft white chalk.

287, 340. Firm white chalk.

387. Rather hard white chalk. A slice showed the usual characters of the lower part of the *Terebratulina gracilis*-zone. "Spheres with a fairly robust shell are abundant; *Globigerinæ* common and large; shell-fragments few, but two large *Inoceramus*-prisms occur in the slide."

411. Hard creamy-white chalk. In a slide of this Mr. Hill finds "shelly fragments abundant, some consisting of many united prisms (*Inoceramus*); spheres are abundant and robust. It clearly comes from the zone of *Inoceramus mytiloides*."

423, 427. Very hard, creamy-white chalk, like the more solid parts of the Melbourn Rock. This is confirmed by the examination of a slide prepared by Mr. Hill from 427, which has the structure of the lower part of the Melbourn Rock.

430. A soft, greyish, marly chalk. Of this Mr. Hill reports that it presents a marked contrast to the preceding, and resembles the marly chalk of the *Belemnitella plena*-zone near Hitchin.

443, 470, 476, 500. Firm greyish-white chalk, 443 being rather hard, the others softer; 500 is as white as 443.

510, 511, 512. Soft grey chalk.

517, 525. Rather hard grey chalk.

530, 550, 556, 558. Rather hard grey Chalk Marl.

569, 579. Firm grey Chalk Marl. Having cut slides from both, Mr. Hill writes that they are characteristic Chalk Marl, a certain amount of fine siliceous matter being present in the calcareous mud of the matrix. 569 is rather sandy and shelly, the shell-fragments being large for Chalk Marl. 579 is less sandy and shelly. Glauconite-grains are common, but small in 569; larger in 579.

585. A rather hard, grey, sandy and micaceous chalk. Abundant flakes of white mica and minute glauconite-grains can be seen with a lens. Mr. Hill describes this as containing "much inorganic matter, fine quartz-sand to a large extent replacing the shell-fragments of the chalk, and still finer argillaceous matter preponderating over the calcareous material in the amorphous matrix. There is much glauconite in small grains, but these are larger and darker than those in the overlying beds, marking an approach to the Greensand. A number of foraminifera and a few calcareous spheres occur."

587, 588. Greenish, sandy, glauconitic and micaceous marl. In microscopic structure this might be called Greensand, as both quartz and glauconite-grains are abundant and of fair size: but there is still a considerable amount of amorphous calcareous matter. Mr. Hill writes that it much resembles a slide from the base of the Chalk Marl near Tring, believed to have come from Ivinghoe, but is rather coarser in grain. It may therefore be regarded as a fine-grained variety of Chloritic Marl.

590? The depth-label of this sample has been lost, but we think the sample must have come from here, for it is a dark-grey sandy marl enclosing large grains of quartz and of glauconite, and containing patches of darker and more sandy material; also two nodules of dark grey phosphate and several fossils (*Pecten interstriatus*, *P. orbicularis*, a small oyster, and many broken fragments of *Inoceramus*). It resembles the representative of the Cambridge Greensand formerly worked at Sharpenhoe in Bedfordshire.

591, 592, 604. Fine-grained, grey, marly, glauconitic and micaceous sandstones, 592 containing a light-brown phosphatic nodule. These much resemble the very fine-grained micaceous sandstones of the Upper Gault or Upper Greensand in Bucks, where the so-called Upper Greensand is thinning out. All are rather heavy in the hand.

613. Lighter-coloured, glauconitic and micaceous sandstone, of much less specific gravity. This Mr. Hill recognizes as an Upper Greensand Sponge-bed. "The chief constituents are quartz-sand, sponge-spicules and glauconite-grains, with a few shell-fragments and foraminifera. These materials are closely packed together, and are cemented partly by crystalline calcite and partly by silica in the amorphous colloid condition. Both calcite and silica seem to permeate the whole rock, and sometimes masses of calcite are surrounded and isolated by the silica. Both seem to have been derived from the organic remains of which the rock must in the first instance have been largely composed, and to a certain extent the two minerals have replaced each other. Thus the siliceous spicules are now almost entirely replaced by calcite-casts (? of their canals); only a few remain in their original state, and in these the spicular canal is usually filled with glauconite. Colloid silica in a globular form is abundant. The glauconite-grains, though abundant, are rather small."

621. A light-coloured siliceous stone of low specific gravity. On examining a slide of this Mr. Hill found it to be an interesting rock. He describes the matrix as "almost entirely colloid silica, partly in minute masses like tiny bits of gum arabic, partly in discs or globules, the latter irregularly scattered in patches. In this matrix are dispersed small grains of quartz, broken sponge-spicules, with a few shell-fragments, and a few foraminifera. The siliceous matrix being comparatively clear, the other ingredients stand out conspicuously."

622, 628. Calcareo-siliceous rocks, heavier than the last, and externally resembling calcareous malmstone. Describing a slide cut from 622, Mr. Hill says "the mass of it consists of definite, separate calcite-crystals of irregular size, set in a matrix of fine calcareous material. There are many spicules, the silica of which is replaced by calcite, and there are also many residuary spicular canals in glauconite. Quartz-grains, though abundant, are well separated, but no colloid silica of any kind was observed. Glauconite-grains are small and not abundant." 628 is a similar rock.

632. A fine, dark-grey, silty clay. This, as would be expected from its external aspect, is regarded by Mr. Hill as a Gault clay. Under the microscope the mass of it is seen to be a fine, brownish, inorganic material, with much fine quartz-sand. Small glauconite-grains occur, but not abundantly, and there are also broken glauconitic spicular casts. Thread-like filaments (? mica-flakes in transverse section) are common, and there are some larger crystals whose striation and frayed ends suggest felspar.

658. A dark-grey clay, with a soapy feel; effervesces with hydrochloric acid, and is therefore somewhat calcareous.

670 to 725. Nine samples of dark-grey clays; all very fine-grained, homogeneous Gault clays.

790. A fine, compact, dark-grey clay. This was sliced and examined

by Mr. Hill, who describes it as consisting of very fine argillaceous matter having a brownish tint in thin slice. In it are some large glauconite-grains curiously arranged in rows, and a few small quartz-grains.

796. A sample of dark, dull-green sand, held together by earthy matter. When washed it is seen to consist partly of glauconite-grains and partly of small bits of quartzose and siliceous rocks; the glauconite-grains are quite as numerous as the others, but even-sized and smaller than many of the quartz-grains. Some of the quartz is clear, but most of the grains are dirty from enclosures. There are many rolled grains of lydianite and fine siliceous grit, some of slate and some of a brown rock. A few shell-fragments occur, and under an inch-objective two or three foraminifera were seen, but they are scarce.

800. Grey shelly limestone of Wenlock type, full of brachiopods (many specimens of *Leptæna transversalis*) in a calcified shelly matrix. Another sample is a dull earthy limestone with *Leptæna*, *Orthis*, and other fossils.

802. Dark-grey earthy mudstone, with a shelly layer containing *Leptæna transversalis*, *Pentamerus linguifer?*, *Orthis elegantula*, and other fragments of shells. Another piece of hard grey mudstone with scattered shells.

804, 809. Hard, earthy mudstones, slightly calcareous, with shelly layers, composed chiefly of *Leptæna* and *Orthis*-shells.

827. Two samples of dark-grey calcareous sandstone, with many fossils (*Pentamerus galeatus*, *Orthis elegantula*).

Classification of the Beds.

From the preceding data, and from information given by Mr. Francis, we are able to construct the following tabular view of the succession at Ware:—

	Thickness. Feet.	Depth. Feet.
Alluvium and River Drift	17	17
Upper Chalk	? 183	200
Middle Chalk	227	427
Lower Chalk	163	590
Upper Greensand	40	630
Gault	166½	796½
Wenlock Beds	35	831½

In comparing this with the section previously published it will be seen that we have been able to divide the Chalk in accordance with modern views, and that we have considerably curtailed the thickness of the Upper Greensand, which had been previously given as 77 feet, although one of us had suggested that this was too great a thickness. The older account places the base of the Chalk Marl at 558 feet, but the specimens prove that it lies much lower than this; the sample from 585 feet is undoubtedly a chalk, though very micaceous and glauconitic: that from 591 is undoubtedly a greensand; the junction must therefore lie between these depths, and we

have found reason to place it at about 590 feet. The Upper Greensand, then, is about 40 feet thick, and cannot be more than 44 feet.

With regard to the supposed Lower Greensand, we cannot accept the idea of its existence. The material found at the base of the Gault, and resting on the Wenlock Beds, is just such a basement-bed as might be expected in such a position. It consists of the débris of Palæozoic rocks mixed with glauconite, and so far as its mineral composition goes it might belong to any member of the Cretaceous series. One of us had already suggested that this bed might be the base of the Gault, though without any evidence. It is satisfactory to be able to take out so very thin a representative of the Lower Greensand.

As a matter of fact, there is generally a bed of such sand at the base of the Gault; not only does it occur at Folkestone above the basement nodule-bed, but also below London, in the boring at Meux's Brewery, where the base of the Gault is described as follows [1]:—

Greensand and clay	2¼ feet.
Seam of phosphatic nodules and quartzite-pebbles	½ foot.

Again, at Richmond, the lowest bed of the Gault is very sandy, full of glauconite-grains, and passes down into a pebble-bed consisting of phosphate-nodules, fragments of Palæozoic rock, and sand, from the same source.[2]

We do not know whether any phosphate-nodules occurred at Ware, but the 18 inches of sand is evidently similar to that in the same position at Richmond and London.

With regard to the Wenlock Beds, these were originally described by Mr. Etheridge in 1879 as 'Wenlock Shale'; but Mr. Hopkinson in the paper before mentioned states that there were thin intercalated beds of limestone. This is confirmed by the samples before us, which are all either of hard mudstone or of limestone; and also by the specimens preserved in the Museum of Practical Geology. Mr. Rudler informs us that the core referred to by Mr. Etheridge is over 3 feet long and has a circumference of 3½ feet; it consists of dark-grey mudstone, slightly calcareous, and including thin bands of brownish limestone; it is marked as coming from 826 feet. This is probably the depth of the base of the core, as samples of similar material were sent us from 827 feet. There are also at Jermyn Street three specimens from 820 feet, one a limestone containing *Strophomena rhomboidalis*, the others of mudstone containing *Phacops caudatus* and *Ischadites Kœnigi*.

In calling these beds 'Wenlock Shale' Mr. Etheridge probably used the term in a stratigraphical, not in a strictly lithological sense; but considering the frequency and purity of the limestones, which are not merely calcareous concretions, it is quite as likely that the beds represent the Wenlock Limestone as the Wenlock Shale. It will be safer, therefore, to speak of them merely as Wenlock Beds.

[1] Quart. Journ. Geol. Soc. vol. xxxiv. (1878) p. 912.
[2] *Op. cit.* vol. xl. (1884) p. 737.

V. The Cheshunt Boring.

General Note.

This boring, like that at Ware, was made for the New River Company. Its site is on the western side of the high road between Cheshunt and Wormley, where the word 'Turnford' is engraved on the old 1-inch map; hence it is known to the officials of the New River Company as the Turnford boring, but as this is only the name of a hamlet and not that of a village, it seems better to speak of it as the Cheshunt boring, as has already been done by one of us.

The surface-soil at the site is gravel; the level is about 110 feet above Ordnance datum, and only a few feet above the alluvium of the River Lea, which lies to the eastward.

So far as we can learn, the boring was begun in 1878, and was completed in 1879. The results were partly noticed by Mr. Etheridge and by Mr. Hopkinson[1]; a more detailed section was given by one of us,[2] and this was afterwards corrected and much enlarged, partly from an inspection of specimens.[3]

Mr. J. Francis, the Engineer of the Company, having kindly furnished us with specimens of all the samples retained at his office, we are now able to add some further details and to prepare a still more accurate account. Unfortunately, however, no samples from the Upper or from the Middle Chalk seem to have been preserved, so that we cannot fix the horizons of the Chalk Rock and of the Melbourn Rock as we hoped to have done.

Before noticing these samples we may supply a deficiency in the former account of the section, and that from information also given by Mr. Francis. No record of the top beds had come to hand, and we were without information as to the Drift and the London Clay, and with but little as to the Reading Beds and the Thanet Sand. The succession of beds above the Chalk is now given as follows:—

		Thickness. Feet.	Depth. Feet.
[River Drift.]	Malm [? loam]	4½	4½
	Gravel	10	14½
[London Clay, 30 feet.]	Yellow clay	¾	15¼
	Blue clay	15¼	30½
	Blue sandy clay	12	42½
	Blue shelly clay [basement-bed]	2	44½
[Reading Beds, 36 feet.]	White sand	4½	49
	Mottled clay	4	53
	Grey sand with lignite	27½	80½
Grey and black [Thanet] sand		10½	91

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[1] Pop. Sci. Rev. n. ser. vol. iii. (1879) p. 290, and Trans. Watford Nat. Hist. Soc. vol. ii. pt. 7 (1880), p. 241.

[2] Trans. Herts. Nat. Hist. Soc. vol. iii. (1885) p. 176.

[3] Geol. Surv. Mem. 1889, 'The Geology of London and of Part of the Thames Valley,' vol. ii. p. 50.

The division between the Reading Beds and the Thanet Sand is rather doubtful, and the depth to the Chalk is 11½ feet less than was given before. This is for the most part, if not altogether, explained by the surface from which the above measurements were made being at least 8½ feet, and perhaps rather more, below the original surface of the ground from which the earlier measurements were started.

Samples and Section.

We now give descriptive notes of the samples sent us by Mr. Francis, including the remarks made by Mr. W. Hill on eight specimens which he was kind enough to cut and examine for us.

At 630 feet. Rather hard, whitish chalk, evidently belonging to the top of the Lower Chalk.

At 722 and 733 feet. Hard, light-grey chalk.

At 734. Soft, grey, marly chalk.

At 736. Firm grey chalk.

At 746. Very hard, whitish, gritty chalk, with large scattered grains of glauconite. This was sliced by Mr. Hill, who describes it as very full of shell-fragments with many foraminifera and calcareous spheres, and a few sponge-spicules replaced by calcite. Moreover the rock is indurated by infiltrated calcite. It resembles the hard rock-bed which occurs in the Chalk Marl of Risborough (Bucks), except that it contains much less quartz and glauconite.

At 750 and 754. Soft, grey, marly chalk.

At 759 and 760. Rather hard grey chalk. That from 760 has been cut, and is described as a chalk-marl with rather a large quantity of even-sized shell-fragments, with here and there a larger prism of *Inoceramus*-shell. The quartz-grains are also small. Glauconite, calcareous spheres, and foraminifera are present, but not abundant.

At 762. Soft, grey, marly chalk.

At 763, 764, 765. Firm, grey, silty chalk.

At 770. Soft, dark-grey chalk-marl.

At 771. Hard grey chalk. This was sliced, and found to be a shelly chalk-marl with many grains of glauconite; but with only a very few small grains of quartz: it is practically without quartz-sand.

At 774 and 779. Mottled dark- and light-grey marls.

At 780. Rather hard light-grey chalk.

At 784. Grey, mottled, sandy and glauconitic marl. This consists largely of quartz-sand and glauconite-grains, which are thickly packed in a matrix of amorphous material, the proportion of calcareous atoms not being large. We thought this might be the base of the Chalk Marl, but Mr. Hill regards it as Greensand. There are no spicules or foraminifera, and very few shell-fragments.

At 790. Soft, fine-grained, greenish-grey micaceous and glauconitic sand.

At 800. Hard, grey, siliceo-calcareous rock. Under the microscope this was found to consist of sponge-spicules replaced by calcite, with scattered grains of quartz and of glauconite and a few foraminifera. There are also many glauconite-casts of spicular canals. All these ingredients are cemented together by crystalline calcite, which is made opaque by a previously existing matrix of finely granular calcite mixed with fine, amorphous, inorganic material. Silica occurs throughout the slide, and in open spaces where it can be well viewed it appears to be both colloid and chalcedonic. Colloid globular silica is also present, but in patches scattered through the field of the slide.

At 808. Fine grey sand, with much mica and small grains of glauconite.

At 810. Compact, grey, calcareous sandstone, with glauconite and mica.

At 811, 813, 814. Soft fine sand, grey, micaceous, and glauconitic.

At 816. Hard, compact, dark-grey, sandy limestone, enclosing numerous small grains of glauconite and of mica.

At 818. Grey calcareous limestone. Mr. Hill finds that this consists chiefly of calcite, partly in minute crystals and mixed with a small proportion of inorganic matter to form a matrix, partly in larger separate crystals. With these latter are grains of quartz and of glauconite, a few foraminifera (*Globigerina* and *Textularia*), and a few spheres, but no colloid silica.

At 819. A friable, grey, sandy and glauconitic marl.

At 825. A fine calcareous sandstone with large glauconite-grains. This is similar to the last, but differs in having more glauconite in larger grains.

At 836. A dark-grey, silty, and slightly calcareous clay. The microscope shows this description to be correct. There is much fine inorganic material, some fine quartz-sand, and some fine calcareous matter; no glauconite. A similar sample comes from 840 feet.

At 844. A clean, smooth, unctuous clay.

At 850. A somewhat silty grey clay.

Eight samples between 860 and 914 are ordinary, clean, grey Gault clays.

At 925. Hard grey clay, with phosphate-nodules and some small specimens of *Inoceramus concentricus*.

928 to 980 (eight samples) are compact grey clays.

Mr. Francis informs us that there was at or near the base of the Gault (980½ feet) a layer of dark sand like that at Ware. One of us has also seen a sample of phosphatic nodules and broken belemnites coming from 980½ feet, so that there can be little doubt that the basement-bed is like that at Richmond and at Meux's, namely, a nodule-bed with greensand above.

Below the Gault hard dull-purple shale or mudstone was found, and similar material was penetrated for 29½ feet. This rock was identified as Devonian by Mr. Etheridge, from its fossils. It is said that the dip was ascertained to be about 30° S.E. A sample sent us by Mr. Francis has tool-marks on the outside, and if these are taken to be horizontal the divisional planes show a dip of 40°. There are specimens in the Museum of Practical Geology at Jermyn Street.

From the data above given and those published in the 'Geology of London' we have constructed the following abstract of the beds proved by this boring:—

	Thickness. Feet.	Depth. Feet.
River Drift and Eocene Beds	......	102½
Chalk, with many layers of flints	260½	363
Chalk, described as 'chalk-rock'	15	378
Hard tough chalk	46	424
Chalk, described as 'chalk-rock'	6	430
Chalk of varying hardness, some beds hard, some soft, and some tough. This is probably all *Middle Chalk*	170	600
Chalk, described as hard and tough, with 7 feet of mild chalk in the middle (? *Lower Chalk*)	25	625
Hard whitish chalk	35	660
Tough light-grey chalk	73	733
Alternations of soft grey marl and hard chalk	29	762
Firm, grey, silty chalk and chalk-marl, with two beds of hard grey chalk	17	779
Chalk Marl, passing down into Chloritic Marl	4	783
Upper Greensand. Fine greenish sands, with beds of hard calcareous sandstone at intervals, the last at 825 feet	44	827
Gault. Silty calcareous clays in the upper 20 feet, then compact grey clays, with a bed of greensand and phosphate-nodules at the base	153½	980½
Devonian. Hard dull-purple mudstones	29½	1010

VI. Conclusions.

Amongst points of general interest is the fact that the floor of older rocks has now been struck at a much less depth than before. Ware held the first place with a depth of 796½ feet, but now Culford takes it with only 637½, or 159 less, measuring from the surface.

For the proper consideration of the subject, however, it is needful to refer the depth of the various borings to one level instead of reckoning from the surface, in which latter case the height of the ground affects the result. This height is, of course, a varying factor which has nothing to do with the position of the older rocks, being due to actions that have taken place in late geologic time, to erosive work of a purely superficial kind, affecting the thickness of the Tertiary beds and sometimes of the Chalk, but disconnected from all other beds beneath. The depth from the surface, depending as it does on the level of the ground, is a matter of no moment, except locally.

The only standard of level that naturally occurs to us is the Ordnance datum, or mean sea-level, as that is the only one easily and universally available. In the following remarks, therefore, we shall refer to depth below Ordnance datum. In the case of Culford and Ware, however, the reference of the figures to this datum makes no difference, the two sites being at about the same level.

In this matter it is noteworthy that heretofore the oldest rocks yet reached by deep borings in South-eastern England are those that come to the highest level; Silurian beds having been reached at Ware, Devonian at Cheshunt and London (Meux's), Red Rocks of doubtful age, but now generally thought to be Old Red, at Streatham (where something suggested that the passage-beds from Silurian to Old Red had been touched), Crossness, Kentish Town, and Richmond, this last being the deepest, and Carboniferous beds at Harwich and Dover, as well as at Burford, in the Jurassic tract of Oxfordshire.

Again, Ware is the most northerly of the deep borings in and near London, where they most do congregate, and it shows not only a slight northerly rise of the floor of older rocks, but also a rise in the divisions of those rocks, resulting in Silurian beds coming next beneath the Gault.

These two points tend, therefore, to give some slight support to the view that the old rock at Culford may be pre-Carboniferous, and perhaps pre-Silurian, in age. Not that this support is worth much, but, having so little whereon to float conclusions, even a straw must be taken into account.

On the other hand, however, the fact that at Harwich, which is nearer to Culford than any other of these deep borings, it is Carboniferous slate that has been found, and that this is, in some respects, not unlike the harder parts of the Culford rock, naturally leads the sanguine to hope, if not to expect, that the latter too may be of Carboniferous age. Should this view be right, the likelihood of still higher Carboniferous and coal-bearing rocks occurring underground somewhere in the Eastern Counties is of course greatly increased.

The nearness of older rocks to the surface at Culford was unexpected by us: perhaps, indeed, no geologist would have ventured to predict that such rocks would have been reached there, except by a boring of much greater depth. One might fairly have expected to go at least 1000 feet, and to have found the Lower Greensand and the Jurassic Series well represented, more especially perhaps the latter, seeing that the outcrop in the neighbourhood of Ely is within 20 miles of Culford.

The accompanying table shows the relations of the various borings that reach the older rocks in the London Basin, including therein the Chalk tract as well as that of the Tertiary beds. The point clearly brought out by it is the sinking of the floor of older rocks southward, in the district over which the borings occur, the only exceptions being Harwich, which should come second in the list, and

Dover, which should change places with Richmond, according to northing. Both exceptions, however, are far eastward; but while the former shows an easterly fall, the latter shows a rise in that direction. They are also the only two borings that have proved the presence of Carboniferous beds.

That the northerly rise of the older rocks continues underground beyond the neighbourhood of Culford we can hardly expect, and we know that, farther northward (in Norfolk), at Yarmouth, Norwich, Holkham, and Lynn, such rocks have not been reached by borings taken to a deeper level than that at Culford.

It is noteworthy that the range of depth to the older rocks, over so large a district as that within which the borings occur, varies only to the extent of about 700 feet, and this is between Culford and Richmond, a distance of more than 70 miles.

Site of Boring.	Overlying Formations.	Nature of Older Rock.	Depth.	
			Below Ordnance Datum.	From the Surface.
			Feet.	Feet.
Culford (Suffolk)...	Cretaceous...	Doubtful	528?	637½
Ware (Herts.)	Cretaceous...	Silurian	686?	796½
Cheshunt (Herts.)	Tertiary ... Cretaceous	Devonian	870	980½
Kentish Town (Middlesex)...	Tertiary ... Cretaceous	Red and Grey Rocks	930	1113½
London, Meux's (Middlesex)...	Tertiary ... Cretaceous Jurassic ...	Devonian	981	1066
Crossness (Kent)	Tertiary ... Cretaceous	Red and Grey Rocks	1003	1008
Streatham (Surrey)	Tertiary ... Cretaceous Jurassic ...	Red and Grey Rocks	1010	1120
Harwich (Essex)	Tertiary ... Cretaceous	Carboniferous .	1015	1029
Dover (Kent) ...	Cretaceous Jurassic ...	Carboniferous .	? 1120 or +	1157
Richmond (Surrey)	Tertiary ... Cretaceous Jurassic ...	Red and Grey Rocks	1220	1237

Discussion.

The President pointed out the importance of the work in which Mr. Whitaker, one of the Authors, had been engaged for so many years in recording all borings and well-sinkings, and (as in the present cases, described by the Authors) adding most valuable information as to the contours of the ancient underground ridge of Palæozoic rocks, on which the Secondary rocks rested unconformably over so large an area of the Eastern and South-eastern Counties of England.

Prof. Boyd Dawkins agreed with Mr. Whitaker in his general conclusions as to the Palæozoic floor rising to the north, and pointed out that the sequence of the Palæozoic rocks in the London area and the district to the north was exactly that which may be studied at the surface in South Wales, Gloucestershire, and Somersetshire. He further called attention to the fact that the non-discovery of coal-bearing rocks in this area was not to be taken as proving the non-existence of coalfields in the London Basin. It merely implies the existence of a pre-Carboniferous region between Ware and Streatham, and between Richmond and Erith, analogous to that which separates the coalfield of South Wales from that of the Forest of Dean, and from that of Gloucester and North Somerset. The shale at Culford seemed to him probably of Silurian age, and quite unlike any Yoredale or other shales belonging to the Carboniferous period. The shale at the bottom of the Harwich boring is of Yoredale age, and contains *Poseidonia*.

Prof. Judd asked Mr. Whitaker whether he had considered the evidence supplied by the Northampton borings as to rocks of the Palæozoic plateau. We have evidence there of red rocks with Carboniferous plants and other fossils, and he was not sure that the beds occurring at the bottom of the Richmond boring might not be the same abnormal Carboniferous rocks.

Mr. Topley also spoke, and Mr. Whitaker briefly replied.

33. Contributions *to the* Geology *of* British East Africa.—Part I. *The* Glacial Geology *of* Mount Kenya.

By J. W. Gregory, D.Sc., F.G.S. (Read May 23rd, 1894.)

Contents.

I. Introduction.

In the discussion as to the respective merits of the rival theories concerning the causes of former glaciation, few lines of work seem likely to yield better results than the study of the originally greater extension of glaciers in tropical regions. When therefore, on emerging from the dense forests of the lower slopes of Mount Kenya, I came upon a series of old moraines, not 10 miles from the Equator and far below the level of the existing glaciers, my interest was at once aroused in the additional problems presented for solution.

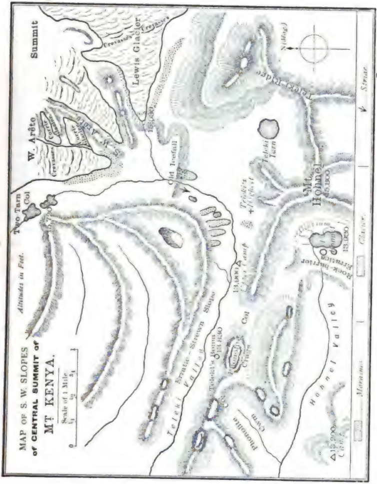
Mount Kenya is situated in long. 37° 20′ E. and lat. 0° 6′ S.; it rises to the height of approximately 19,500 feet, and covers an area of about 700 square miles. It consists in its lower part of a huge pile of volcanic ash and débris, with a low gradient, rising from 7200 to 10,200 feet, densely covered with forest and bamboo-jungle. Above this frown steep craggy slopes of coarse agglomerates, ash, and lava, while the whole is surmounted by a rugged pyramidal peak which is part of the central core of the old volcano.

The central peak is of such excessive steepness that the snow is scattered irregularly over it, instead of forming a 'calotte' or snow-cap, similar to those on Kibo (the higher summit of Kilima Njaro) and Chimborazo. The snow accumulates in the hollows and on the slopes with lower gradients; from these snow-fields a series of glaciers flow down into the valleys.

The existing glaciers occur mainly on the western and south-western slopes of the mountain. The three principal classes of glaciers are represented; there are the normal valley-glaciers, of which the largest is the Lewis glacier, named after the late Prof. J. Carvell Lewis, whose premature death cut short a career of such brilliant work on glacial geology. This, and two similar valley-glaciers to the north-west of it, flow from nevé-fields to below the snow-line. Their lower courses are bordered by moraines. The glaciers are crevassed, especially in the steeper portions of their course, and are separated from the nevé-fields by fairly large *berg-schrunds*. The second type consists of the 'corrie' or 'hanging

Fig. 1.—*View of the central Peak of Mount Kenya; with the Lewis Glacier.*
(The Teleki Valley, with a grove of *Senecio kenyensis*, is seen in the foreground.)

Fig. 2.


MAP OF S. W. SLOPES
of CENTRAL SUMMIT of
MT KENYA.
Scale of 1 Mile
Altitudes in Feet.
Two Tarn Col
W. Arête
Summit
Lewis Glacier
Old Icefall
Teleki Tarn
Teleki Ridge
Mt. Hohnel
15,800
Erratic - Strewn Slope
Teleki Valley
Hohnel Valley
Phonolite
Rock-barrier
Moraines
Glacier
Striae

2 o 2

glaciers'; the two largest of these are situated on the south-western face, just north of the south-western arête. They end in vertical ice-cliffs 200 to 300 feet high. Below these are huge masses of fallen ice-blocks, by the consolidation of which the third type or the 're-cemented glaciers' have been formed: these are here tributary to the valley-glaciers.

The snout of the Lewis glacier ends at the height of 15,580 feet, but the two others reach a lower level, as they occur in sheltered valleys and drain larger collecting-grounds: they come down to about 15,300 feet.

II. The former Glaciation.

As has already been remarked, the lower slopes of the mountain are swathed in so dense a cloak of vegetation that it is impossible, on a hasty march through that area, to learn much regarding its geological structure. At the level of 9800 feet, however, I found some erratics of coarse andesite, some of which measured about $4 \times 4 \times 3$ feet. They were much weathered and rounded, but their surfaces were still grooved; they were certainly not *in situ*, and did not appear to be ejected blocks. I halted the caravan, and cut my way through the neighbouring bamboo-jungle, in order to see whether I could obtain any evidence of the former existence of a parasitic cone at this point. No such evidence, however, could be found, and the irregularly undulating nature of the ground seemed to indicate that the rocks are a series of erratics overlying or weathered out of an old moraine, rather than an extra-morainic fringe.

As soon as we emerged from the forests, we came on abundant evidence of former glaciation, for we struck at once on a terminal moraine. Huge erratics lay strewn about, and I soon noted among them specimens of most of the coarser rocks which were afterwards found in the central portion of the mountain. Small sections cut by streams showed that these occurred in a stiff, greasy clay, formed of a re-deposited volcanic ash: it was of the type familiar as the matrix of a boulder-clay. The scenery also, with its irregular undulations, its numerous swampy, mossy hollows, and its scattered boulders, was highly characteristic of old moraines.

Above the moraine rises a steep, glaciated, rocky slope, over 1000 feet in height, from the summit of which the first view of the general structure of the mountain may be obtained. The base is seen to consist of a vast forest-covered declivity, rising with a gradient of about 1 in 18 to the level of 10,200 feet. Between the forests and the base of the rock-slope is the undulating tract of moraine, which I could now see was continuous as a belt all round the mountain. From the edge of the rock-slope rises a series of alpine meadows furrowed by deep valleys, the walls of which are crowned by picturesque pillars and crags of agglomerate and lava. From this last zone abruptly towers the pile of rocks that forms the great central peak.

The rock-slope can be clearly seen from Laikipia, and is shown

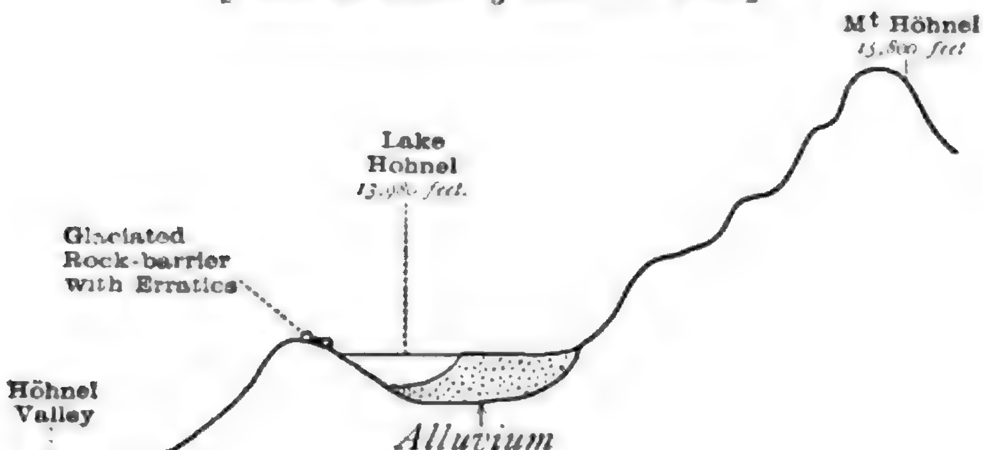
in von Höhnel's sketch from Ndoro; its nature appeared to me rather puzzling, as there were points in it which did not accord with the theory of its being a crater-wall. Its *moutonné* surface, however, showed that it had been greatly worn by glaciers, and it doubtless represents the site of the old ice-fall that once occurred here when an ice-cap covered the upper part of the mountain.

In the whole of the alpine zone of Mount Kenya there is abundant evidence of former glaciation. The rocks on the face of the rock-slope, the bosses that rise from the peat-swamp above it or are exposed on the flanks of the valleys, are all *moutonnées.* Erratics and perched blocks are numerous on the sides of the valleys and even on the summits of the ridges that separate them. Three final proofs were the discovery in the higher parts of the valleys of glaciated lake-basins, of a series of terminal moraines, and finally of well-preserved striæ. It is, I think, desirable to describe examples of each of these in detail, so that the foregoing statements may be the more readily checked by future visitors to the mountain.

(1) *Lake-Basins.*—The example of these which best shows a glacial origin is that which I have named Lake Höhnel (see fig. 3).

Fig. 3.—*Section through the cirque, on the W. side of Mount Höhnel, and its lake-basin.*

[Natural scale: $\frac{1}{3}$ inch = 1 mile.]



It is situated in a cirque on the western face of Mount Höhnel, and has its longer diameter running north and south. Between the base of the cliffs of the cirque and the lake is a swampy plain formed by the tumbling of talus from the crags above. The lake is nevertheless at its deepest near the eastern shore, and apparently shallows gradually to the west. On this side it is bounded by a bare rocky barrier, the whole of which is *moutonnée,* while some enormous andesite erratics are perched upon it, in positions which they could not possibly have held unless transported by glaciers. For the sake of avoiding unnecessarily controversial topics, it may be advisable to leave untouched the subject of the possible glacial origin of cirques, although the alternative theory of waterfall action is clearly inapplicable here. I do not think that anyone could contest the glacial

origin of this lake-basin, unless he were ready to adopt the extreme position of denying the glacial erosion of any of the small Alpine tarns and lakelets; and this is admitted by many of those who are most resolutely opposed to such a theory of formation for the greater lakes of Switzerland and Scandinavia, and the lochs and fiords of North-western Europe.

(2) *Old Moraines.*—Of the numerous moraines connected with the present glaciers, a group in the upper part of the Teleki Valley serves as the best example; I have never seen any old set of moraines preserved with more diagrammatic simplicity than these. The first three stand out from the north wall of the valley as clearly as so many railway-embankments. They are composed simply of piles of andesite-boulders, with a smaller proportion of clay than is usual in Alpine moraines. They are about 30 feet in height and reach nearly across the valley. A small tarn occurs behind the uppermost one, and the drainage from this—as well as the stream that flows from the glaciers—is forced by the moraines to the south side. A little farther up, the valley bends abruptly northward, and is crossed by a steep rock-slope that doubtless marks the site of an old ice-fall. From this point a median moraine runs along the valley, and marks the line of junction of the Lewis glacier with that which flowed from the other two.

The Map which accompanies the present paper (fig. 2, p. 517) shows the general arrangement of this group of moraines.

(3) *Striæ.*—The rocks on Mount Kenya are for the greater part coarsely crystalline lavas which weather irregularly and rapidly, and would do so even if they were not subjected to such exceptionally powerful disintegrating agencies as those which operate on the summit of Kenya. I did not therefore expect to find striæ on unexposed surfaces. A few likely situations on lava-bosses on the sides of the valleys were selected and the turf removed; striæ were then found in every case; they were usually very well marked, and especially so on the rocks near the great bend of the Teleki Valley, at the point marked in the map (fig. 2, p. 517). The other localities are not marked, as the striæ were there not so well preserved and might easily be overlooked by anyone who was not prepared for a little trouble and had not had some practice in observing striæ.

The boulders in the upper moraines are seldom striated.

III. The Nature and Age of the Glaciation.

In the preceding pages evidence has been adduced to prove that the existing glaciers on Kenya were once far more extensive than they are at present. They are now merely 'stream-glaciers.' Erratics, however, occur on the crests of the ridges, as on that on the north side of the Teleki Valley; the ice must therefore at one time have completely filled up the valleys, as they were then in existence. Moreover, the great terminal moraine which probably extends all round the mountain could not have been formed by any

system of mere valley-glaciers, as the moraine occurs in places at the foot of a rock-slope which is concentric with the peak and at some distance from the mouths of the radial valleys. This terminal moraine could alone have been formed by an ice-sheet which filled up the whole of the valleys then in existence and spread out over the whole surface of the mountain as a 'calotte.' The ice-cap would have been much like that which now fills up the crater of Kibo, or that which Mr. Whymper has so well described as covering the dome of Chimborazo, or again that which the Rev. Maxwell Close has invoked to explain the glacial phenomena of Iar-Connemara.[1]

It must be remembered, therefore, in studying the glacial evidence near its lowest margin, that we have to deal with an ice-sheet and not with a mere valley-glaciation.

Former Extent.—The glaciers now terminate at a height varying from 15,300–15,580 feet, or we may take the mean as 15,400 feet. The old moraine at the foot of the ice-fall occurs at the level of 10,000 feet, while the erratics can be seen down to 9800 feet. How much farther they extended it will be very difficult to determine, owing to the denseness of the bamboo-jungle that covers this region of the mountain. The glaciers, however, unquestionably extended for at least 5400 feet below their present limit.

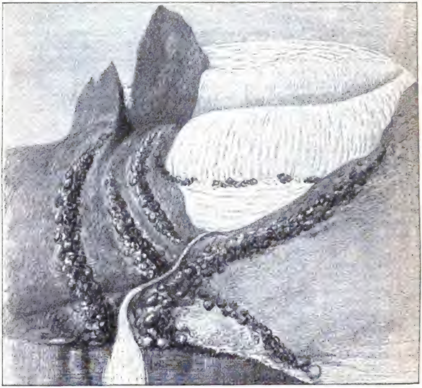
Age of the Glaciation.—This is another problem that can only be approximately determined. The upper set of moraines in the Teleki Valley are very perfectly preserved, but there are full-sized specimens of the arborescent *Lobelia gregoriana*, Baker fil., and *Senecio kenyensis*, Baker fil., growing upon them. Though the former of these may reach the height of 25–30 feet, they are probably of very rapid growth. The great terminal moraine is certainly much older; it is weathered, the slopes are rounded, gullies and valleys have been cut through it and the sides covered with turf; the boulders are covered with moss and the striæ have been erased; the *roches moutonnées* have lost their polished surfaces, and only the deeper grooves and the general form remain to attest their true origin. Great trees, whose age must be measured by centuries, grow in sheltered places on the moraine.

There can be no reasonable doubt that the glaciation took place at a date which, judging by historical standards, must have been very far distant; it was probably anterior to the introduction of the tribes who now inhabit the district, and may date back to the period of the maximum extension of the lakes of the East African lake-chain, of which the present members are the greatly diminished representatives.

In reference to the age, it may be asked whether the glaciers are now still receding. Fig. 4 (p. 522) shows the snout of the Lewis glacier encircled by a set of terminal moraines; the uppermost of these, however, has been burst through by the glacier, and therefore it has recently advanced. The advance, however, has so far been a very

[1] G. H. Kinahan and Maxwell H. Close, 'The General Glaciation of Iar-Connemara,' Dublin, 1872, p. 18.

Fig. 4.—*Terminal Moraines of the Lewis Glacier.* (Diagrammatic.)



small one, and the close proximity of the different members of this series suggests that the glacier has been for some time almost stationary, but subjected to numerous slight oscillations. These may result from irregular annual variations in the snowfall, but it is not improbable that they may have been produced by the well-known oscillation of the ice-periods [1] which results from the periodical oscillation in the temperature of the globe.

IV. The Causes of the Glaciation.

The main geological interest of the former extension of the Kenyan glaciers, at a period geologically recent, is the fact that the

[1] M. Rykatschew, 'Ueber den Auf- und Zugang der Gewässer des russischen Reiches,' 11ter Suppl. Bd. zum Repert. f. Meteor. St. Petersburg, 1887, p. 53.
Ed. Brückner, 'Klimaschwankungen seit 1700, nebst Bemerkungen über die Klimaschwankungen der Diluvialzeit,' Geogr. Abh. vol. iv. Heft 2 (1890), pp. 244–255.

mountain is situated directly on the Equator. Bearing in mind that the glaciation of Northern and Central Europe, North America, and New Zealand took place in times which are geologically *approximately* synchronous, the discovery of a great extension of the Equatorial glaciers seems at first sight to support the idea of the universal refrigeration of the globe and to necessitate some astronomical explanation of its cause.

Theories of the universality of glaciation are here ignored because of the absence not only of any traces of former more extensive glaciation from the tropics, as in the Andes and Kilima Njaro, but also from the Cape.

The absence of evidence in the first of these three is very striking. In spite of the extensive glaciers now in existence on the higher peaks of the Andes, there is practically no evidence of their former greater extension. Mr. Whymper kindly tells me that only in two cases did he see any traces of glaciation below the limits of the present glaciers; the chief of these were some decayed *roches* below his second camp on Chimborazo, but it was only a little below the level of the neighbouring Glacier de Débris.

Nor has any such evidence been recorded from Kilima Njaro, though over 100 Europeans have visited it. The majority of these, however, have been sportsmen or naturalists with no geological training, and the others have not reached the level which the glaciation attained. Both Hans Meyer[1] and L. Purtscheller are well acquainted with the appearance of recent glacial phenomena, but it is possible that they may have failed to recognize the weathered traces of old moraines. Some doubt may therefore be felt as to the negative evidence in this case.

Another negative record is that of Prof. Henry Drummond, who says, "In East Central Africa not a vestige of boulder-clay, nor moraine matter, nor striæ, nor glaciated surface nor outline is anywhere traceable;" and he adds "It has been my lot to have had exceptional opportunities of studying the phenomena of glaciation."[2]

The third case is the most instructive. The one region of Africa that one would expect to have been glaciated, if any were, is Cape Colony: but it seems almost certain that, in spite of some old records, this district cannot have been glaciated since at least Cretaceous times, for otherwise erratics of the conspicuous 'Pipe-Amygdaloids' of the Stormberg series must have been carried on to the surrounding lowlands.

It does not therefore seem necessary to consider here the theory that explains glaciation as being due to the alteration of the position of the earth's axis of rotation, notwithstanding the remarkable astronomical results recently obtained, which show that some shifting of

[1] Meyer speaks of moraine-like ridges round the snow-fields, but explains them as merely talus accumulations ('Across East African Glaciers,' pp. 312–313).

[2] 'Tropical Africa,' 4th edit. 1891, p. 198.

the pole almost certainly does take place. As this, however, is periodical and of very slight amount, its effects would be insignificant.[1]

Another favourite theory—the agency of a different distribution of land and water—cannot be applied in this case, unless one is prepared to maintain the existence of Gondwanaland to a very late Tertiary date, which probably few geologists would be prepared to do.

It seems therefore necessary to fall back on a purely local explanation, of which the natural one is elevation, owing to which a greater mass of the mountain was upreared above the snow-line. This elevation may have been effected by either or all of the three following agencies :—

(1) An elevation of the whole region.

(2) Local earth-movements of the Mount Kenya district.

(3) By the height of the volcano before it was reduced to its present level by denudation.

In regard to the first, there seems no sufficient evidence to establish the existence of any subsidence of the country for 5000 feet. The fiord-like estuaries that run up into the coastal plain, such as Port Reitz, or the harbours of Kilindini, Takaaungu, or Khilifi, indicate a submergence of only slight amount. The coral-reefs of the coastal plain show changes of level all along the coast which vary in amount from 20 to 50 feet.

There may be evidence of a greater and older submergence in the occurrence of some limestones on the Magarini Hills, though it is probable that the rocks have been carried there (for some economic purpose) by some exceptionally energetic native. But even if they be in place, they indicate a subsidence of only some 300 feet, which would be quite useless.

It may be suggested that the depression, which formed the channel of over 1000 fathoms in depth that broke the former connexion between Madagascar and the mainland, indicates a subsidence of the whole region of the required amount. But the differences in the fauna and flora show that this was probably much older than the period of maximum glaciation, while the subsidence along this line is more likely to have counterbalanced a simultaneous elevation of the

[1] The principal references to the subject of the variation of latitude are as follows :—

S. C. Chandler: six papers in Astron. Journ. Nos. 248–251, 267, 277, and Monthly Notices R. Astron. Soc. vol. liii. (1893) pp. 119–120. For subsequent discussion, see F. Folie, 'Essai sur les Variations de Latitude,' Bull. Acad. R. Sci. Brux. sér. 3, vol. xxvi. (1893) pp. 577–613 ; A. d'Abbadie, 'La Fluctuation des Latitudes terrestres,' Bull. Astron. vol. ix. (1892) pp. 89–102; Simon Newcomb, 'On the Dynamics of the Earth's Rotation with respect to the Periodic Variations of Latitude,' Monthly Notices R. Astron. Soc. vol. lii. (1892) pp. 336–341 ; H. G. van de S. Bakhuyzen, 'Variations of Latitude deduced from the Observations of Polaris made at Greenwich 1851–89,' *op. cit.* vol. li. (1891) pp. 286–306 ; W. G. Thackeray and H. H. Turner, 'On the Variations of Latitude as indicated by Recent Observations at the Royal Observatory, Greenwich,' *op. cit.* vol. liii. (1893) pp. 2–11 ; W. G. Thackeray, 'Latitude Variation and Greenwich Observations 1851–1891,' *ibid.* pp. 120–123, pls. iii.–v., and *ibid.* pp. 292–296 ; G. C. Comstock, 'The Secular Variation of Latitude,' Amer. Journ. Sci. ser. iii. vol. xlii. (1891) pp. 470–482.

land-masses on either side than to have been part of a widespread equal earth-movement.

There is therefore no evidence on the coast of changes of level sufficiently recent or important to account for the glaciation.

The second suggestion, namely, that it was due to local earth-movements, seems much more probable, as in the great rift-valley a few miles to the west there is evidence of very extensive faulting and earth-movements of Pleistocene age; some of these have cut through the great pile of Settima, the companion volcano that rose opposite Kenya on the western side of the Laikipia plateau. If there were no elevation on the coast or at Kilima Njaro, a differential movement of only 1 in 250 would give the required elevation on Kenya.

The third cause no doubt contributed something, as not only must the cone once have been very much higher than it is at present, but the slopes would then have been more suitable for collecting snow than the precipitous crags that now form the central summit of the mountain. It is unfortunately impossible to determine from the data at present available the exact height of the original crater, as, until it is known how much the forest-clad slopes have been lowered by denudation, one cannot estimate the height and extent of the base from which the crater rose. Kibo rises about 2000 feet higher than Mawenzi, and the parallel between these, the newer and older eruptive centres of Kilima Njaro, must be very similar to that between Kibo and Kenya. If we assume that the slopes of Kenya in its prime were at the same angle as those of Kibo, then an addition of 2000 feet to the altitude of Kenya would form a peak of almost exactly the right diameter.

We may thus account for 2000 of the 5400 feet required. But an increase in the size of the snow-fields would lead to an increase in the length of the glaciers, which would thus reach a lower level. To take an illustrative case from the Swiss glaciers. The following glaciers are arranged in pairs, and the members of each pair are closely adjacent and under apparently similar conditions; thus the two Grindelwald glaciers are parallel, adjacent, flow from the same mountain-axis, and both to the north; the Aletsch and Fiesch glaciers are also similar, but flow both to the south. The figures are taken from Heim's 'Handbuch der Gletscherkunde,' p. 73:—

Name of Glacier.	*Area of ice-field in square kilometres.*	*Alt. of snout of glacier in metres.*	*Depth of snout below the nevé-line in metres.*
Gorner	69	1840	960
Zmutt	27	2100	650
	Area of collecting-ground.		
Aletsch	99·54	1353	1400
Fiesch	33·57	1500	1300
Unteraar	22·0	1879	850
Oberaar	6·7	2243	500
Unter Grindelwald...	28	1080	1650
Ober Grindelwald ...	12	1320	1400

This shows that in each case the glacier with the larger collecting-area goes the lower and farther below the nevé-line. The distance to which this 2000-feet addition to the height of Kenya would carry down the glaciers cannot be determined; it would depend (1) on the rate of the motion of the glaciers, which is probably high—owing to the steepness of the gradient and the enormous diurnal range of temperature: I had intended to measure this, but the refusal of my men to approach the snow-line rendered it impossible to do so; and (2) on the rate of ablation, which would probably be very great and would lessen the length of the glaciers.

The fact, moreover, that the valleys are glaciated to their bottoms and that perched blocks still surmount the crests show that there has been no very great denudation in the alpine zone since the maximum glaciation. Thus, though there may have been a considerable lowering of the central plug which now forms the summit since the time of maximum glaciation, in the later stages, as when the glaciers were depositing the terminal moraines of the Teleki Valley, the entire crater-walls had disappeared. Therefore, though the lowering of the summit by denudation has no doubt helped to restrict the downward extension of the glaciers, as these were more extensive in times later than the destruction of the crater, this factor can account for only a fraction of the balance of 3400 feet.

In spite, however, of the absence of evidence of earth-movements on the coast or of a glaciation of Kilima Njaro, there is one line of argument which shows that the elevation was not limited absolutely to the Kenya district. On the higher summits of Kilima Njaro, Ruwenzori, Elgon, the mountains of Abyssinia and the Cameroons, there is an alpine flora quite unlike anything in the lower country of Equatorial Africa. This must once have extended across the lower plateaux and retreated to the mountains as the land subsided to a warmer and lower level. In the 'Geographical Journal'[1] is a map illustrating the present and former distribution of this alpine flora, showing that a downward extension of the glaciers for a little over 5000 feet would enable this distribution to be effected without the intervention of any universal African ice age, and merely as a result of its greater elevation. The fact that the fauna extended to the Cameroons is of interest, as the submerged fiord beyond the mouth of the Congo shows that great subsidence has occurred in that region.[2]

[1] J. W. Gregory, 'Contributions to the Physical Geography of British East Africa,' 1894, vol. iv. p. 289.

[2] Enrico Stassano, 'La foce del Congo,' Atti R. Accad. Lincei, ser. 4, vol. ii. pt. 1 (1886), pp. 510–513; see also Ernst Linhardt, 'Ueber unterseeische Flussrinnen,' Jahresber. Geogr. Gesellsch. München [1890–91], 1892, pp. 26–27, 41–42. It is fair to note, however, that this case is not regarded as a proof of subsidence by J. Y. Buchanan, 'On the Land Slopes separating Continents and Ocean Basins, especially those on the West Coast of Africa,' Scottish Geogr. Mag. vol. iii. (1887) pp. 222–223.

V. Climatic Conditions during the Period of Maximum Glaciation.

The former distribution of the alpine flora of Equatorial Africa is an indication of the different climatic conditions that resulted from or were concomitant with the maximum glaciation. An attempt will be made in this part of the paper to determine the meteorological conditions of Equatorial Africa at that period.

In the first place, it will be advisable to consider the changes in the general conditions of the atmospheric circulation, that would have resulted from the elevation of Mount Kenya for over 5000 feet, and then the effects of these changes on the atmospheric pressure and thus on the winds and rains.

The first change to be noticed is that the whole of the uplifted region would be colder. The average rate of decrease is generally taken, following Herschel, at 1° F. for every 300 feet of ascent; and though in many later cases which have been more accurately observed the rate of diminution of temperature has been increased, it may be advisable to take this rate—so as not to exaggerate the amount. But it must be remembered that the rate of cooling increases both with the ascent and the seasonal descent of the isotherms. The annual mean, however, for the carefully collected data given by Hann [1] from the observations on the Théodule, when reduced to feet and Fahrenheit, also gives 1° F. for 300 feet. As these results were obtained at the height of over 10,000 feet, and well above the snow-line, the conditions of that case are probably fairly analogous to those on the higher African peaks.

The mean temperature will therefore have been 17° F. lower than at present. This would have a treble influence: (1) the air would contract in bulk; (2) the saturation-point would be lowered, and the air become drier; (3) there would therefore, owing to the increased precipitation, be more snow than under existing conditions. Now all these three factors tend in the same direction, viz. an increase of barometric pressure on the lower regions and a depression of the isobaric surfaces. Consequently, there would be at night, when the cold is greatest, an inset current at a high level toward the mountain. This further helps the depression of the isobaric surfaces, and there would thus be at night a downrush of air along the slopes, similar to that well known in the Alps, with a high-level inset current sweeping in to the mountain and carrying the damp air from the surrounding lowlands on to the snowclad summit.

In the daytime the conditions would be reversed; the sun would exercise enormous power, the surface of the mountain would be heated, ablation would be very rapid, the air would become moist, the

[1] J. Hann, 'Ueber das Klima der höchsten Alpenregionen,' Zeitschr. oesterreich. Gesellsch. Meteor. vol. v. (1870) p. 197.

See also Hann's recent memoir, 'Weitere Untersuchungen über die tägliche Oscillation des Barometers,' Denkschr. k. Akad. Wissensch. Wien, vol. lix. (1892) pp. 297–356.

isobaric surfaces would rise and air rush in from below. There would thus be a high-level radial outflow, and a low-level inflow.

The air would not, however, be free to move radially from the mountain equally in all directions, for along the Equator there is a prevailing westerly wind. This is due to two factors: as the heated air rises, if its proper easterly motion were to remain the same, its radius vector would increase; its velocity has therefore, by Newton's second law, to diminish, and it lags behind as a westerly wind. Then the air that rushes in to the Equator from north and south has a lower eastward velocity than points on the lower latitude; it therefore also drags to the west. Therefore any low-pressure area on the Equator is simply in the position of a stationary eddy on a westward-flowing stream, and is supplied mainly from the east. Thus Uganda, as it is in the neighbourhood of the low-pressure area of the Nyanza, has its prevalent winds from the east. But east winds in this part of Africa are dry ones, because they arise on the dry barren steppes or 'Nyika' between the mountains and the sea; for the monsoons blow parallel to the coast, and thus cut off any large wind-supply from the Indian Ocean. The wet winds are those from the great forest-regions of the west; thus it is that the snow-line is so much lower on the western sides of Kilima Njaro and Kenya than on the eastern; in the former, the glaciers reach the level of 13,800 feet on the western side and only 18,700 on the eastern. The different amounts of snow on the two sides of the main southern arête of Kenya show that the same condition holds there.

The points to which these observations have led up are:—

1stly. The meteorological conditions of Kenya and doubtless also of Kilima Njaro[1] are very different from those on the surrounding plains, for there is a daily reversal of the wind-direction, so that westerly winds can come in at all times of the year and not only during the changing of the monsoons. There is therefore no such sharp differentiation on these mountains into wet and dry seasons.

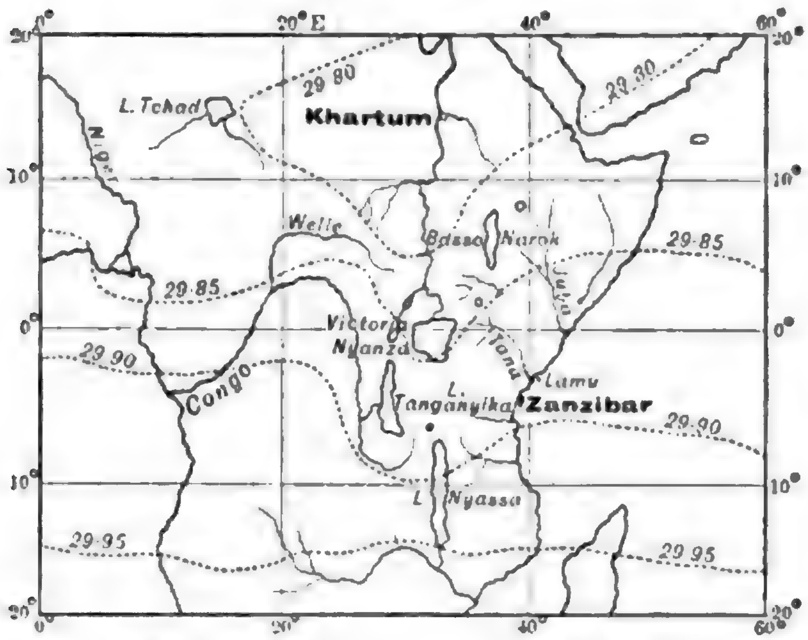
2ndly. If the whole region were raised 5400 feet, an enormous tract of country would be placed under these conditions, and not only a few isolated peaks.

Let us next consider what influence would result therefrom on the conditions of atmospheric circulation, and thus on the rains and plant-distribution.

At the present time this region of Africa appears to be one of low pressure. If we take Dr. Buchan's isobaric charts for each month and calculate from these the mean for 5 points—viz. the north end of Lake Nyassa, Zanzibar, the first point at which the Congo crosses the Equator, the Nyanza, and Khartum—we get indications that the low-pressure area of Arabia and the Sahara has a branch up the Nile Valley to the south. This is shown in fig. 5. In the time of

[1] Hans Meyer has discussed ('Across East African Glaciers,' pp. 307–310) the winds of Kilima Njaro, which are not now under the same conditions as those of Kenya, for it is over 200 miles south of the Equator, and therefore is within the region of the trade winds, and not of the Equatorial westerly drift. It is, moreover, nearer the southern line of maximum pressure.

Fig. 5.—*Isobaric Map, showing the low-pressure area in Equatorial Africa.*



The dotted lines ...... = mean isobars.

the maximum glaciation, on the other hand, a high-pressure area would have occurred over Kenya, Kilima Njaro, Elgon, and doubtless also the Ruwenzori districts; this would have resulted from the cold, dryness of the air, abundance of snow, and inset high-level current.

The influence of this on the rains would be as follows:—

(1) This high-pressure area would deflect the normal westerly drift of the air along the Equator, and therefore more air would reach this region from the damp forest-land of the west than does so at present.

(2) The whole region, moreover, would be subject to daily reversal of the direction of the wind, and thus there would be much greater local irregularities, and no sharp differentiation into wet and dry seasons. The rainy seasons are now very well defined on the lowlands. They occur:—

On the coast at Lamu, Mombasa, etc., from April to August and for parts of December and January.
In South-western Kikuyu from February to May.
In Uganda from September to November and in April.
Around Basso Narok (Lake Rudolph) in April and May.
In Southern Abyssinia in March and April.

(3) The maximum rainfall now occurs in the forest zone on Mount Kenya, between 7000 and 11,000 feet, though at some seasons it may rise higher, just as in the Alps it is in the winter at from 3000 to 4000 feet, and in the summer occurs above the highest peaks.[1] But when the ground was higher the line of maximum rainfall would not rise to the same amount, owing to the resultant lowering

[1] J. Hann, 'Die jährliche Periode des Regenfalles in Oesterreich Ungarn,' Zeitschr. oesterreich. Gesellsch. Meteor. vol. xv. (1880) p. 264.

of the temperature. At the period of maximum glaciation it would therefore occur relatively lower than at present, and there would thus be a considerable rainfall over areas that are now very sparsely watered.

The results on the rainfall of the changes that would have occurred at the time of the maximum glaciation would therefore have been:—(1) an increase in its amount; (2) a relative lowering, and therefore widening, of the surface of maximum rainfall; (3) the more even distribution of the rain throughout the year.

The results on the vegetation of the district would have been very great. Much of the scrub which now covers the country with its spine-like or narrow leaves, and succulent leafless herbs and trees, which are all specialized to secure a minimum of transpiration, would have been replaced by vegetation of a more normal and luxuriant growth, and better adapted for animal food. The forests that now occur as belts beside the rivers would have spread out as wide tracts of primeval forest, similar to those of the Congo and the Aruwimi, which are now limited to the western side of the Tanganyika rift-valley. Hence in the time of maximum glaciation the food-supply for insects and small mammals would have been distributed very differently from what it is at present, and there would have been fewer, if any, of the waterless wastes that now present barriers to animal migration.

VI. Summary of Conclusions.

1. That, by the discovery of moraines, striæ, glacial lake-basins, perched blocks, and *roches moutonnées* below the present limit of the Kenyan glaciers, it is proved that these must once have extended for at least 5400 feet below their present level.
2. That at the time of maximum glaciation Mount Kenya was covered by a great ice-cap or 'calotte,' and did not merely support a system of valley-glaciers.
3. That the glaciation was due to the former greater elevation of Mount Kenya, which has been reduced by subsidence and denudation. The theory of an universal glaciation is unnecessary, and is opposed by many facts in African geology.
4. That the glaciation affected the adjoining mountains, including Kilima Njaro, Ruwenzori, Elgon, and Abyssinia, is rendered highly probable by the facts of botanical distribution.
5. That the meteorological changes concomitant with the maximum glaciation, and also due to the elevation, would have been the formation of a high-pressure area and an increase in the amount of the rainfall, its more equable seasonal distribution, and a lowering and widening of the surface of maximum rainfall.
6. This would have led to a great change in the distribution of animal- and plant-life.

34. *On the* Stratigraphy *and* Physiography *of the* Libyan Desert *of* Egypt. By Capt. H. G. Lyons, R.E., F.G.S. (Read May 23rd, 1894.)

[Plate XXI.—Map.]

Contents.

I. General Description.

The work of Geheimrath Karl A. von Zittel,[1] as a member of the Rohlfs Expedition of 1874, has furnished us with an accurate geological description of the western oases of Egypt, which we can use as a starting-point for the further exploration of the Libyan Desert to the north and south of them, and his detailed sections and lists of fossils are of invaluable assistance in correlating the strata met with in various parts of this area.

Still, I cannot find that much has been done since Dr. Zittel's work except by Dr. Schweinfurth, Sir J. W. Dawson, Prof. Hull, Prof. Walther, Prof. Mayer-Eymar, and Mr. E. A. Floyer in the Fayum, the Nile Valley, and various parts of the eastern desert, while the western desert seems to have remained almost unexplored.

In December 1893 and January 1894, when on a patrol visiting the oases of Kharga and Dakhla, and the desert routes to the south of them, I had opportunities of making a few observations in this portion of the desert which are, I venture to think, of some interest.

These I have more recently (April 1894) been able to amplify by a ride through the more northern part of this western desert, the route followed being from the pyramids of Giza to Dêr Macarius, the easternmost monastery in the Wadi Natrun or the Valley of the Natron Lakes; thence along the valley some 20 miles to Dêr Baramus, the westernmost of the four Coptic monasteries. From this point I turned S.S.W. and went as directly as possible to the northern end of the Baharia Oasis, thus traversing an area shown as geologically unknown in Dr. Zittel's[2] map. From this oasis I returned to the Nile by almost the same road as that traversed by Prof. Ascherson[3] in 1876.

South of the oases of Kharga and Dakhla, the part of the desert traversed is included between two lines, each about 100 miles long, drawn southward from these oases and following the old trade

[1] 'Palæontographica,' vol. xxx. (1883) p. 1.
[2] *Ibid.* map.
[3] Mitth. geogr. Gesellsch. in Hamburg, 1876–77.

routes known as the Arbain road and the Terfau road. Between these two roads the intervening desert was crossed in two directions, and was found to be a sandstone plateau, falling slightly towards the north as it neared the Cretaceo-Eocene limestone-escarpment of the oases.

Nowhere were any hills of a greater height than 200 to 250 feet above the plain to be seen, though at a distance, when exaggerated by mirage, and especially when on the sky-line, small hillocks appeared to be high hills several miles distant, and Dr. Schweinfurth, in his map of the Kharga Oasis, records such high hills in the desert to the south-west.

Speaking generally, the Eocene beds stretch away northwards from the line of the southern oases, where they end in an escarpment facing south, until they pass under the Jebel Ahmar Sandstone to the north of the Baharia Oasis, and under the Miocene beds to the N.W. in the neighbourhood of the Siwa Oasis. These Eocene rocks are underlain by Upper Cretaceous rocks, which form the floors of the oases of Kharga, Dakhla, and Farafra, and the bases of the cliffs which hem them in on their eastern, northern, and north-western sides; while to the south and south-west the ground rises gently to the Desert plateau, consisting of the Nubian Sandstone, which forms an immense tableland, rising and falling with gentle slopes, hardly ever forming hills of any considerable height, but weathering into flat-topped masses and truncated pyramids, which stand out as witnesses of the amount of erosion which has taken place. These isolated hills [1] are a special feature of the Libyan Desert, and contrast strikingly with the sharp peaks occurring in the crystalline areas, and with the rounded granite hills formed sometimes of enormous boulders split off by the variations of temperature to which they have been subject, and now crumbling away through the breaking-up of their constituent minerals by the same agency.

The earliest rocks occurring in this area are the crystalline rocks exposed at the First and Second Cataracts and at Kalabsha (lat. 23° 30′ N.), which have been frequently described [2] and have been classed as Archæan. The only exposures that I know of in this part of the western desert are, one at the small hill of Jebel Abu Bayan, 10 miles south of the Kharga Oasis, and the other south of the Dungul springs, and between them and the village of Tomas, on the Nile, a few miles above Korosko. This latter spot I have not visited, but at Jebel Abu Bayan the rock is a coarse-grained hornblendic granite, with large crystals of pink orthoclase, and is apparently identical with that described by Prof. Bonney.[3] The hill also contains dykes of a fine-grained granitic rock, and some of a diorite, as well as one of a fine-grained basalt.

[1] Zittel, 'Palæontographica,' vol. xxx. (1883) p. 38; Walther, 'Die Denudation in der Wüste,' p. 64, Leipzig, 1891, sep. cop., & Abh. d. k. sächs. Gesellsch. d. Wissensch. vol. xvi. pp. 407 *et seqq.*

[2] Sir J. W. Dawson, Geol. Mag. 1884, pp. 289, 385, etc.; T. G. Bonney, Geol. Mag. 1886, p. 103; C. A. Raisin, Geol. Mag. 1893, p. 436.

[3] Geol. Mag. 1886, p. 105.

II. The Nubian Sandstone.

Wherever the junction can be seen these rocks are overlain by the Nubian Sandstone, which becomes coarser at its base, usually forming a quartz-conglomerate. In no case have I ever observed any sign of the metamorphism of the sandstone by the granite as recorded by Mr. E. A. Floyer [1] and Johnson Pasha.[2] I have not seen the localities referred to by them, but such metamorphism is totally at variance with the mode of occurrence of these rocks in the area that I have examined. The only case of an alteration of the sandstone which I have met with is at Jebel Burka, 20 miles W.N.W. of Wadi Halfa, where a mass of olivine-dolerite has forced its way through the sandstone, porcellanizing and altering it for a few inches at the junction.

The Nubian Sandstone varies much in colour and durability, according to the amount of staining by oxides of iron and manganese and the amount of cementing silica. Lenticular beds of clay occur which sometimes extend for several miles, and these are considerably developed at the base of the hills east of Wadi Halfa (lat. 21° 55′), while on the western bank of the river at this point a bed of stiff blue clay may be seen in some ancient Egyptian tombs. A similar clay has been recorded as occurring at the Shebb wells, 100 miles W.N.W., and I saw a sample of stiff blue clay brought up from a depth of about 160 feet from the surface at the village of Mushia in the Dakhla Oasis, where it underlay the water-bearing sandstone. I am not, however, in a position to bring forward evidence of a continuous stratum of this blue clay extending over a large area, and serving to hold up the water in the overlying beds, though Mr. E. A. Floyer [3] describes it as continuous over a large tract, and overlying the granite floor on the east side of the Nile between lat. 23° and 25° N.

These beds seem to be lenticular deposits rather than continuous beds, and the appearance of the Nubian Sandstone, wherever I have seen it, is strongly suggestive of an estuarine deposit. The strata are often strongly false-bedded, and fine clay-partings occur from time to time. Nodules [4] of peroxides of iron and manganese are very widely distributed, especially in the portion containing the fossil trees (*Araucarioxylon* and *Nicolia*), and owing to their black colour, metallic ring, and fantastic shapes these nodules have been constantly described by travellers as lava, volcanic bombs, etc. A small hill, Jebel Karan, at the southern end of the Kharga Oasis has been mapped as a 'black basalt hill,' whereas it is nothing but a small sandstone knoll that has its sides covered with these nodules, and with fragments of dark-red sandstone from the bed forming the top of the hill.

The sandstone itself varies from a dark purple-red mass of quartz-grains cemented by silica, coloured by the oxides of iron and manganese, hard and refractory, breaking through the quartz-

[1] Quart. Journ. Geol. Soc. vol. xlviii. (1892) p. 577. [2] *Ibid.* p. 483.
[3] *Ibid.* p. 576. [4] Zittel, *op. jam cit.* p. 58.

grains as readily as through the cement, to a white, soft, friable sandstone which can be crumbled between the fingers.

In the neighbourhood of Wadi Halfa, and especially on the eastern bank, lenticular deposits occur (of 2 to 5 miles and more in length) of an iron-ore deposit usually strongly oolitic in character; plant-remains in the form of fragments of fossil wood occur in it, but no other fossils, so far as I have been able to discover. These beds are certainly lagoon deposits formed in secluded pools or backwaters where marsh vegetation flourished, and the iron deposit was formed similarly to the bog iron-ore deposits of the Swedish lakes.[1] The usual thickness of these beds is about $1\frac{1}{2}$ to 3 feet, and at Wadi Halfa from two to three of them are exposed in the cliff-section at various levels.

Prof. Hull[2] considers that the Nubian Sandstone was "deposited within the waters of a vast inland lake, occupying the greater portion of Northern Africa," but I cannot help thinking that, so far as Egypt and Nubia are concerned at all events, its mode of occurrence, lithological character, etc., point to an estuarine deposit which was gradually invaded by the Upper Cretaceous sea as subsidence continued. As I have not been able, in the area I am describing, to distinguish any one part of the sandstone as being of different age from the remainder, I shall consider the whole of it as being Nubian Sandstone of Cretaceous age, as I believe it to be, and not as being of Carboniferous[3] age in the lower part. Perhaps it is only in the eastern parts of Egypt, and in the Sinai peninsula and Palestine, that true Carboniferous deposits were laid down.

The better and harder varieties of this sandstone owe their toughness and durability to the siliceous cement which binds the quartz-grains together, and usually the darker and more iron-stained is the sandstone, the more there is of the cementing silica. Its origin is no doubt due to the same agency as that which has replaced the woody structure of the fossil trees, to which I shall refer again later. The strata are usually almost horizontal, being bent into very slight anticlinal and synclinal folds, which sometimes extend over such wide areas as often to render the dip barely noticeable.

III. The Cretaceous and Eocene Strata.

The Upper Cretaceous beds[4] which overlie the Nubian Sandstone consist of the *Exogyra Overwegi*-series, amounting to about 500 feet of alternating bands of sandstone, clay, shale, and limestone, which contain a large amount of rock-salt and gypsum disseminated throughout. These are succeeded by green and grey shales, which are overlain in their turn by a white limestone.

[1] Geikie, 'Text-book of Geology,' 3rd ed. 1893, p. 146; Roth, 'Allgemeine u. chemische Geologie,' vol. i. (1879) p. 597; Winchell, 'Iron Ores of Minnesota,' Geol. Surv. Minn. Bull. no. 6 (1891) p. 221.

[2] Trans. Victoria Inst. vol. xxiv. (1890) p. 317.

[3] Walther, *op. jam cit.*

[4] Zittel, *op. cit.* pp. 61 *et seqq.*

These Cretaceous rocks, making their appearance first in the Nile Valley near Esna, skirt the Eocene escarpment, of which they form the base, as far as the oases of Kharga, Dakhla, and Farafra, where they are exposed over a large area forming the floors of those oases.

In the Baharia Oasis, 5 miles N.N.E. of the village of Zubbo, I found a bed of *Exogyra*, examples of which Dr. Zittel has identified as undersized specimens of *Exogyra Overwegi*. Thus the sands, marls, and loam occurring in this oasis are of Upper Cretaceous age, and members of the *Overwegi*-series, although they occur here at most 100 feet below beds of the Upper Mokattam series.

An outlying mass of the *Exogyra Overwegi*-series occurs at Bir Murr, 80 miles south of the Kharga Oasis, and perhaps the limestone [1] recorded as occurring at the Selima Oasis is another outlier of these beds.

In the neighbourhood of Cairo the Cretaceous beds are brought up by faults at Abu Roash, 6 miles north of the Giza pyramids (described by Prof. Walther), and at Jebel Atakka, near Suez. North of these Upper Cretaceous beds, the Eocene stretch away, forming the desert plateau, and are divided by Zittel [2] into

(*a*) the Upper Eocene beds.
(*b*) the Mokattam series.
(*c*) the Libyan series.

The lowest of these consists generally of limestone-beds, with some of a more sandy and marly character, and are characterized by *Operculina libyca* and *Alveolina*. The Mokattam beds consist of a lower portion of white limestone mainly characterized by banks of *Nummulites gizensis*, and an upper portion of brown-coloured clay, loam, and sand, with beds of limestone, and banks of oysters (*Ostrea Cloti*, *O. cairensis*, etc.).

At the north-east and east of the Baharia Oasis the Upper Mokattam Beds, characterized by *Ostrea Fraasi* and *O. Cloti* (as kindly determined by Dr. Zittel), occur 30 miles north-east and 20 miles east of Upper Cretaceous beds containing *Exogyra Overwegi* in the oasis, and with a difference in altitude of less than 200 feet. As there is no marked dip of the beds, we have evidently an overlap of the remainder of the Cretaceous beds and the Libyan and Lower Mokattam Beds of the Eocene, and this inference is borne out by the short distance between the Cretaceous and Miocene outcrops to the west on Dr. Zittel's route to Siwa.

The Upper Eocene rocks have at present only been recognized in two localities, namely, near the Siwa Oasis and on an island in the Birket-el-Kurun in the Fayum.

IV. The Miocene and Pliocene Strata.

To the west and north-west this Eocene series passes under Miocene [3] strata in the neighbourhood of the Siwa Oasis, which

[1] W. Willcocks, 'Report on Perennial Irrigation and Flood Protection for Egypt,' Cairo, 1894, App. iii. p. 5.

[2] Zittel, *op. jam cit.* pp. 96 *et seqq.*

[3] *Ibid.* pp. 128 *et seqq.*

consist of a series of limestones and calcareous sandstones, and marls and clays of marine origin, overlain by freshwater beds, also of Miocene age. These last consist of limestones and beds of quartzose sandstones having the grains bound together with a siliceous cement indistinguishable in hand-specimens from the Jebel Ahmar Sandstone. The uppermost freshwater beds are sandy, with layers of fine-grained chalcedonic quartz.

The rocks of the Wadi Natrun south of the Natron Lakes are, I think, of Miocene age, and possibly of the freshwater series, though I have not at present any definite evidence to produce on this point. Lithologically they appear to agree closely with the freshwater beds of Siwa as described by Dr. Zittel, but further examination of them is necessary.

Marine Miocene beds occur also between Cairo and Suez, at Jebel Geneffe and also between Jebel Atakka and Jebel Gallala in Wadi Baida.

Overlying these Miocene beds of the Wadi Natrun is a sandstone, usually grey to yellow in colour (though here and there patches occur of a dark red to almost a black colour, due to oxides of iron and manganese), moderately fine-grained, of average hardness, and intensely tough, a toughness due to the siliceous cement binding the grains. This is the form in which it occurs at Jebel Ahmar, near Cairo, whence it has often been described.[1]

In some parts it contains fossil trees (principally *Araucarioxylon*, *Palmoxylon*, *Nicolia*, etc.[2]), and the principal localities are the 'Petrified Forests' 12 miles E. of Cairo, Kum el Khashab (12 miles W. of the Giza pyramids), and the desert west of the Fayum and south of the Wadi Natrun, as far as lat. 29° N.

It often happens that the toughest and most durable sandstone occurs near large deposits of the fossil trees. Thus Jebel Ahmar is on the east and Jebel Raibun on the west of the petrified forest near Cairo; while at Kum el Khashab, near Giza, the same sandstone occurs, and 20 miles W.S.W. of Dêr Baramus, in the Natron Lakes, I came upon an exposure of this tough, almost black sandstone, where the desert was covered with numerous fossil trees.

Over all this area we meet with fossil wood in pieces of all sizes, from small fragments to masses 1 or 2 feet in length, and up to trunks of 30, 40, and even 50 feet long, and 2 to 3 feet in diameter, all completely silicified. These are scattered broadcast over the surface of the sandstone area, sometimes grouped rather closely for several miles. They are all lying horizontally in every direction, half embedded in the sand, the only cases of pieces found in an upright position being where they had been set up as road-marks by the Arabs. As the southern limit of the sandstone was approached trunks grew scarce, and finally only small fragments occurred for the last 20 miles.

[1] Newbold, Quart. Journ. Geol. Soc. vol. iii. (1848) p. 335; Dawson, Geol. Mag. 1884, p. 385; Schweinfurth, Zeitschr. deutsch. geol. Gesellsch. vol. xxxv. (1883) p. 718.
[2] A. Schenck, 'Palæontographica,' vol. xxx. (1883) pt. ii.

In general appearance, in mode of occurrence, and even, according to Dr. Schenck,[1] in some of the genera, they are the same as those occurring in the Nubian Sandstone south of the oases of Kharga and Dakhla.

Schweinfurth[2] has pointed out that at Mokattam this sandstone (which may be called the sandstone of Jebel Ahmar,[3] where it is typically developed, and whence it has been frequently described) lies unconformably on the Eocene beds; A. B. Orlebar[4] has described it as resting on Miocene beds in the neighbourhood of the Middle Station of the old Suez Railway; I found it overlying the Miocene beds on the south side of the Wadi Natrun, while at its southern margin it overlies a thick bed of *Ostreæ* (*O. Fraasi* and *O. Cloti*) which is of Upper Eocene (Upper Mokattam) age, thirty miles north-east of the Baharia Oasis.

A tongue of it, 25 miles broad, crosses the road from the village of Mandisha (Baharia Oasis) to Bahnessa (lat. in the Nile Valley), commencing 40 miles from Mandisha, and ending at a point rather above the banks of *Nummulites gizensis* in the Mokattam series. Thus it seems that this Jebel Ahmar Sandstone is later than the marine Miocene beds, being perhaps of Upper Miocene age, and it may be of a not very different age from the freshwater Miocene beds in the neighbourhood of Siwa, as suggested by Zittel.[5] It is this sandstone which furnishes the quartz-sand of the dunes of this western part of the Sahara, till we come to the outcrop of the Nubian Sandstone.

Of later age than these are the beds south of the Giza pyramids, containing *Clypeaster ægyptiacus*, and the sea-beaches of Cairo, to which a late Pliocene age has been assigned.

In the oases, and especially in the southern part of Kharga, there is a considerable area covered by a fine sandy loam, slightly calcareous, unstratified, containing rootlet-tubes and occasionally land-shells. This is evidently the result of fine sand and dust drifted by the wind till it was retained and bound together by vegetation, when the oasis was more cultivated than now. In recent times, from want of cultivation, the loam has been deeply eroded and rapidly removed by the wind.[6]

V. The Anticlinal Folds, and their Relation to the Water-supply.

About 90 miles south of the Kharga Oasis (lat. 23° 20′ N.) is the spring Bir Murr (the bitter well), the first watering-place on the

[1] *Op. cit.* p. 15: species given in columns 1, 3, 5, and 8 are from this Jebel Ahmar sandstone.
[2] Zeitschr. deutsch. geol. Gesellsch. vol. xxxv. (1883) p. 718.
[3] This term seems preferable to that of '*Nicolia*-sandstone,' since that fossil tree is described as occurring both in these beds and in the Nubian Sandstone.
[4] Journ. Bombay Branch Roy. Asiat. Soc. vol. ii. (1845) p. 232.
[5] *Op. jam cit.* pp. 132, 134.
[6] See Richthofen, 'On the Mode of Origin of Loess.' Geol. Mag. 1882, p. 293.

Arbain road leading to Dongola and the Sudan, where caravans water their camels, the water being too salt for men to drink. Geologically it lies in a small depression eroded out of the Cretaceous (*Exogyra Overwegi*) beds, and is situated on the crest of a sharp anticlinal fold.

As this spot furnishes an important clue to the stratigraphy of the desert, I will describe it somewhat in detail. On approaching the spring from any direction, attention is at once arrested by a large bed of white limestone forming a small plateau. The limestone contains many Cretaceous fossils, and is underlain by a bed of *Exogyra Overwegi*. Below this is a series of grey, green, and yellow beds of sand and clay with two or three bands of a calcareous sandstone which weathers to a curious moss-like form; in fact the beds seem to correspond exactly with those of the section [1] at Jebel Ter, near Kharga, and that of Jebel Omm-el-Ghenaim quoted by Zittel from Schweinfurth. The extent of the limestone is not large, not more than about 8 miles from north to south and perhaps as much as 15 to 20 miles from east to west.

The spring itself is situated on the south side of a small fault with a downthrow of perhaps 20 feet to the south, and its direction is about 25° N. of E. for a distance of about a mile. This direction is only maintained locally, for the dips usually observed along the road to the north of these springs for 30 miles are N. N.E., and S. S.W., the strike being some 20° S. of E. Farther north the dip becomes too small to be readily determined, till we come to the Kharga Oasis.

In dealing with rocks such as the Nubian Sandstone, exposed over large areas and not presenting any marked lithological difference between the beds, it is extremely difficult to trace the minor folds across a country where want of water compels the observer to keep to certain definite tracks or to hurry from point to point. This must be my excuse for attempting to elucidate the stratigraphy of the Libyan Desert from such slender data, but the exceptionally uniform character of the beds facilitates the endeavour.

Dr. Zittel has pointed out that the springs of the oases are fed from an underground water-bearing bed which draws its supplies from the rainy districts of Darfur, etc., to the south, and not from the Nile. The water drains down the dip-slope of these sandstone beds, till it can find its way to the surface through fissures in the overlying beds, or by artificial borings, being forced up by the pressure due to the elevation of the gathering-grounds to the south. Thus we shall have the water brought nearest to the surface at points on the axes of the anticlinal folds, and may expect therefore to find that the oases and desert springs are so situated. Should this prove to be the case, the whole question of an increased water-supply for the oases—in other words, their improvement and development—is intimately connected with the geological structure of the area.

To the west of the Arbain road from Assiut to the oases of

[1] Zittel, *op. jam cit.* p. 80.

Kharga and Selima there is another desert track known as the Terfau road, which runs a little east of south from the village of Mut in the Dakhla Oasis for the first 80 miles or so. Although I could not get as far as the well, several considerations caused me to mark a point about 100 miles south of the oasis as the probable site of this well, Bir Abu Tarfa; and after seeing the geological structure of Bir Murr, the conviction grew that it was situated either on the same anticlinal fold as this latter spring, or on the one passing through Wadi Halfa. A few days later, on meeting an Arab who had travelled this road, the distances that he gave me appeared to confirm the inferred position of this well.[1]

If we prolong the direction of the Bir Murr fold eastward, it is found to cut the Nile just by Korosko, and seems to have been the cause of the river making a sudden bend at this locality, impelling it to work along the fold till the easiest point of crossing it was reached.

Passing for a moment to the other desert wells to the south, we find about two days' journey south of Bir Murr a group of wells, known as Kassaba, Nakhlai, and Shebb, the water occurring in each case a few feet from the surface. Between these and the Nile we have the intrusive olivine-dolerite of Jebel Burka, about 20 miles W.N.W. of Wadi Halfa, and about 15 miles down the river from this place a spring runs into the Nile on its western bank, and may be seen trickling over the rocks at low Nile.

The general direction given by these is slightly more south of east than that of the anticlinal at Bir Murr, but it is difficult to avoid the idea that these springs are due to a similar anticlinal fold, which may also have assisted to bring the Archæan rocks of the Second Cataract to the surface.

The next wells to the south are those of the Selima Oasis, which is not at present accessible for geological examination, but the map of this region (W.O. Intelligence Map, No. 662) shows to the south of the oasis "60 miles of alternate ridge and valley," which I believe are the eroded strata of the southern portion of an anticlinal fold, similar to that at Bir Murr, passing through the Selima Oasis. The occurrence[2] of beds of limestone at both these places increases the resemblance. The direction of these ridges is not more south of east than that of the Shebb wells, and, just as we have seen the river deflected by the Bir Murr fold at Korosko, so does it appear possible that the great bend of the Nile between Dongola and Berber may be due to the resistance offered to it by the Selima anticlinal, which turned back the river to wander in the synclinal trough till it found a place to cross in the neighbourhood of the Third Cataract.

North of Bir Murr the granite exposure of Jebel Abu Bayan and the springs in the neighbourhood of Beris at the south of the Kharga Oasis form, with the oasis of Kurkur and the exposure of the crystalline rocks at Assuan, another parallel line, and the section published by Zittel[3] shows the presence of an anticlinal curve in Dakhla. I have already pointed out how these folds appear to have

[1] [Recently (June 1894) the well has been found 50 miles W.N.W. of Shebb.]

[2] W. Willcocks, 'Report on Perennial Irrigation and Flood Protection for Egypt,' Cairo, 1894, App. iii. p. 5.

[3] *Op. jam cit.* map.

[illegible]

VI. The Erosion of the Nile Valley, etc.

Altogether it would seem that the east-and-west folding took place at a time when the Nile, as we know it, had not begun to exist, probably in very late Eocene or early Miocene times; while a later north-and-south folding,[1] culminating in the Nile Valley fault at Cairo and the great Araba fault in Palestine, with a large downthrow to the west, finally determined the line of drainage at a later period. The date of this last folding is not at present very easy to determine; but, as it seems to have been before the Jebel Ahmar Sandstone, it must have been during Miocene times.

As mentioned above, this Jebel Ahmar Sandstone lies on the eroded surface of the Eocene strata, and some of the marine Miocene, *e. g.* that south of Jebel Atakka, near Suez, is deposited in hollows eroded out of the Eocene rocks, so that a certain amount of erosive action had taken place in the earliest Miocene times. Still the main work of carving out the Nile Valley seems to have been done later, after the north-and-south folding had determined the direction of drainage, and after the deposition of the Jebel Ahmar Sandstone as an estuarine deposit, while it was earlier than the late Pliocene beds and sea-beaches which rest against the Nile cliffs of to-day at Cairo and Giza. Thus the early Pliocene times seem to have been the period when the majority of the work was done, though a certain amount was doubtless going on later in post-Pliocene times. Prof. Hull[2] attributes it to the heavy rainfall of a Pluvial Period, but for the reasons quoted above the main part of the work seems to have been done in two stages, and in this I have the support of M. Rolland,[3] who describes heavy erosive action as taking place in Pliocene times in Algeria and a second period of erosion in Quaternary times. Under these conditions, when the northern line of drainage had once been established, we should have the Nile of that period flowing through a plateau and fed by tributary streams from the east and west, by which the upper limestone- and marl-beds would be rapidly eroded away along their dip-slope, leaving an escarpment on the north which was continually being cut back. As the Nile cut its way down through the softer overlying beds it would in time reach the harder Nubian Sandstone or the crystalline rocks, and on meeting them at the points where the anticlinal folds crossed its line the river would tend to move east or west along the obstruction till an easier point was reached. As the Cretaceous limestones and marls were eroded away, the underlying Nubian Sandstone was laid bare and erosion would now go on more slowly, while to the north the limestone escarpment was being cut farther and farther back. By the time the escarpment had been cut back as far as the southern limit of the oases, their springs, bursting out at the base of the cliffs, would enormously increase the rate of erosion.

[1] Rolland, 'Géologie du Sahara,' p. 258.

[2] 'Geology of Arabia Petræa, Palestine, and adjoining Districts,' pt. iv. chap. ii. p. 113, London, 1889.

[3] 'Géologie du Sahara,' p. 260.

Wherever these springs were occasioned by an east-and-west fold they would occur along a considerable length—so as to form a recess such as the Dakhla Oasis, while, where the north-and-south folds came in, the erosive action would be most active in that direction; it is to this that I would attribute the width of Dakhla and the southern end of Kharga from east to west, while the north-and-south folds have determined the longitudinal shape of Kharga.

Evidence of this erosion was found at a spot (lat. 24° 20′ N. and long. 29° 50′ E.) where a small patch of limestone occurred, composed of blocks containing *Alveolina ovoidea*, Schwäg. (Lower Eocene), bound together by a calcareous cement. In parts it was a true limestone gravel. This mass lay directly on the Nubian Sandstone.

The beds of calcareous tufa under the cliffs of the Kharga Oasis containing *Quercus ilex*, etc., as described by Zittel, show that during this earlier (Pliocene) period of erosion the oases attained approximately their present dimensions, while I would refer the tufa deposit to the later post-Pliocene time.

The floors of these oases are now rather below the level of the Nile at Assuan, Kharga being 140 feet, as compared with Assuan, 280 feet above sea-level; but though wind-action may have helped to deepen them, the depressions and elevations of the Nile Valley and neighbouring deserts at various times render it impossible to say to what level the river-action of the past could or could not have worked.

Mr. E. A. Floyer [1] considers that no more rain than falls to-day is required for the districts bordering the Nile, and cites Schweinfurth as inclining to the same opinion. Besides the erosion already described as having taken place in early Pliocene times, evidence in the Libyan Desert tends to show that there was a time, probably post-Pliocene, when the desert was finally being carved and moulded into what is practically its present form, when there was a considerable rainfall over the area, though not necessarily an excessive one. Three hours west of the cliffs overlooking the town of Girga in Upper Egypt there is 8 to 12 feet of flints covering the limestone surface of the desert; these are closely packed together, with a small amount of iron-stained, earthy material between them. While the topmost layer is markedly fractured and blackened by exposure, the lower ones are usually whole and show no signs of blackening. This seems to show that the limestone was quietly dissolved away during a period of rainfall, till the flints accumulated to a considerable thickness. Then the physical conditions changed, and a period of rainfall passed into one of true desert conditions, with fracturing of the flints by variations of temperature, and blackening of the surface-layer by exposure.

All along the foot of the limestone escarpment between Kharga and Dakhla, and under the cliffs on the east side of the former oasis, there are beds of streams with rolled limestone-pebbles and boulders. Some of this is probably due to the rare rain-storms of our own

[1] Quart. Journ. Geol. Soc. vol. xlviii. (1892) p. 580.

time, but I have no doubt that they also represent streams which flowed when the calcareous springs were forming the tufa above mentioned, and when the evergreen oak and other similar plants were growing near.

I would refer to this same period the large gravel-sheets which in Nubia extend for a length of 7 or 8 miles along the Nile bank at Debera, 8 miles north of Wadi Halfa, a period when a more generous rainfall furnished streams which eroded the beds of the neighbouring plateau and fed the Nile, which deposited its beds of alluvium 100 feet above its present level, and maintained the beds of *Ætheria semilunata*, *Cyrena fluminalis*, *Unio*, *Paludina*, and other shells [1] which are found at this level at Wadi Halfa, Debera, Derr, etc. Deposits of impure kaolin in the gullies of the Second Cataract point to the same condition of things, when the rain was weathering the felspars of the crystalline rocks.

Shortly to recapitulate the conditions under which this area has attained its present state, we have firstly an elevation of the Eocene rocks and a certain amount of erosion of them, followed by a depression, at all events in the northern area, where the marine Miocene beds were deposited. A gradual elevation seems to have taken place, and the Jebel Ahmar Sandstone was deposited. An elevation [2] of the area in Pliocene times caused the Nile to erode its bed deeply, and the main work of plateau erosion and the formation of the southern oases was commenced. A depression of the area at the time of the deposition of the late Pliocene sea-beaches,[3] near Cairo, checked this eroding action and probably caused the deposit of the high-level Nile mud with beds of *Ætheria*, etc. A later elevation with a climate of moderate rainfall enabled the river to cut out its present bed below the earlier Nile-mud deposits, and one is almost tempted to go further and attribute the present silting-up of the Nile bed below the First Cataract to a recent depression of the area, at all events to the north, as is shown by Roman tombs near Alexandria, which are now below sea-level.

Much has been made of the fact that the rainfall of to-day has formed deep valleys on the eastern bank of the Nile, but I am inclined to think that, while the rainfall of post-Pliocene times eroded both sides of the river, the physical conditions were widely different. On the west was a gently rising plateau which was not, perhaps, very deeply eroded, and since then thousands of years of wind- and sand-action under desert conditions have ground away and obliterated most of the traces of this rainfall. On the east a high ridge of crystalline rocks gave the streams a more rapid fall, and so vastly increased their eroding power, while then as now they caused precipitation of moisture carried by currents of air from the eastward; thus the gorges and valleys once formed have been kept

[1] Leith Adams and S. P. Woodward, Quart. Journ. Geol. Soc. vol. xx. (1864) pp. 14 and 19.

[2] Jukes-Browne. 'Physical Geology,' pt. iii. ch. ii. 2nd ed. 1892.

[3] These are small patches, too minute to show on any but a large-scale map.

open, even if they have not been much deepened in these later times, and within the past four years three cases have been brought to my notice where torrents have rushed down the eastern valleys, leaving marks which will remain for many years to come.

Besides the geological evidence of the shell-beds and deposits of Nile mud there is also historical evidence of the Nile having reached a higher level in Nubia in ancient times than it does today. On the rocks at Semna, 45 miles south of Wadi Halfa, inscriptions of the XIIth Dynasty (about 2200 B.C.) speak of the Nile flood having reached a point which is 27 feet above its present flood-level. Opposite Wadi Halfa, close to the river-bank, are the remains of a mud-brick temple built in the time of Usertesen I., that is, rather before the Semna inscription, and this temple continued in use down to the time of Ramses XIII. (about 1100 B.C.). The floor of this temple is 14 feet above present flood-level, and any greater rise than this would flood the temple. In the time of Thothmes II. and Thothmes III. (about 1600 B.C.) another temple was built alongside the first, with a flight of steps leading to the river, but they stop with a vertical face some 8 to 10 feet high at a point 19½ feet above present low Nile and more than 7 feet below present flood-level.

At some time subsequent to 1100 B.C., when the temple of Usertesen I. was no longer used, but had fallen into decay, the vaulted mud-brick roof having fallen in, the temple site was flooded to a height of 15½ to 17 feet above present flood-level. Over the drift-sand which had blown in there is a regularly-bedded, fine, white sand, and on this is ¼ to ½ an inch of the finest grey mud-silt which has settled from the ponded-up water. On this silt, which is sun-cracked and rain-pitted by an easterly shower, are the carbonized remains of twigs and grasses, so that the flood evidently came from the Nile and not from a heavy storm in the neighbouring hills, which would have brought down stones, broken pottery, etc.; moreover, a rise in the ground behind the temple would have deflected such a torrent to one side or the other.

Thus we have:—

2200 B.C. A temple at Wadi Halfa, floor 14 feet above present flood-level.

2000 B.C. High Nile level at Semna, 45 miles south, 27 feet above present flood-level.

1600 B.C. Another temple floor about 17 feet above present flood-level, and a stairway ending in a perpendicular face at a point about 7 feet below present flood-level.

After 1100 B.C. The northern temple is flooded, while the other, the Thothmian temple, at a slightly higher level, shows no signs of it, except that at some time, perhaps then, the brick wall round it was doubled in thickness.

Seeing that Wadi Halfa and the Second Cataract are situated on the same series of folds as the wells of Shebb, etc., I would suggest that these variations of the river were caused by earth-movements.

Whatever held up the river to the high level at Semna must have been in the Second Cataract for the most part, as half the amount of rise recorded at Semna would have flooded the temple site at Wadi Halfa.

One point I may suggest as worthy of consideration is that the folds of Farafra and Baharia, and the Shebb and Murat wells, intersect at a point up to which the old caravan-route S.W. from the Dakhla Oasis directly leads. It appears possible, therefore, that in the sandhills of this part there exists, or has existed, another oasis of which we have at present no certain knowledge.

VII. The Origin of the Silicified Wood.

There is no doubt that the siliceous cementation of the sandstone, and the molecular replacement of the woody structure of the fossil trees by silica, are results of one and the same action, which has been ascribed to geysers by Schweinfurth and by Sir J. W. Dawson,[1] while Zittel has distinctly stated that he does not consider this a practicable theory, and points out the absence of siliceous sinter.

Whatever theory proposes to account for the sandstone and trees near Cairo must of course also account for those west of the pyramids of Giza, over the wide tract where I have shown the Jebel Ahmar Sandstone to occur; and, looking at the similarity of the fossil wood from the Nubian Sandstone and of the silica-cemented sandstone from various localities in Nubia, it is hard to avoid the idea that similar agencies worked in each case to produce results so identical. Over the whole of this area, at three points only, viz. Jebel Burka near Wadi Halfa, Mandisha in the Baharia Oasis, and Abu Zabel near Belbeis, have eruptive rocks been recorded, and nowhere have I met with, nor does Zittel in his account of the Rohlfs expedition mention, any siliceous deposit analogous to the sinter deposited by the waters of geyser-springs. Considering the large amount of decaying vegetable-matter there must have been in the sands of an estuary into which such numbers of trees were drifted, I would suggest the action of water holding natron (sodium carbonate) in solution as a possible explanation.

This would act upon the felspar-grains in the sands derived from the crystalline rocks, and would form sodium silicate, while the potash of the felspar would take up the carbon dioxide in place of the silica. On this solution of sodium silicate coming into contact with the decaying vegetation in the sands, the vegetable acids produced in the course of decomposition, and probably carbon dioxide also, would replace the silica which would be deposited as a cement, or as replacing molecule by molecule the woody structure of the trees. And I think we may take this explanation as equally applicable to the Jebel Ahmar or to the Nubian Sandstone, for in the area occupied by the first we have the Natron Lakes with their springs and natron-deposits, while round Bir Malha, south

[1] Geol. Mag. 1884, p. 386.

of the Selima Oasis, are very extensive natron-deposits in the midst of the Nubian Sandstone area.

Dr. A. H. Hooker, Director of the Salt Department of Egypt, informs me that he has seen silicification of woody structure in progress to-day in the Wadi Natrun.

PLATE XXI.

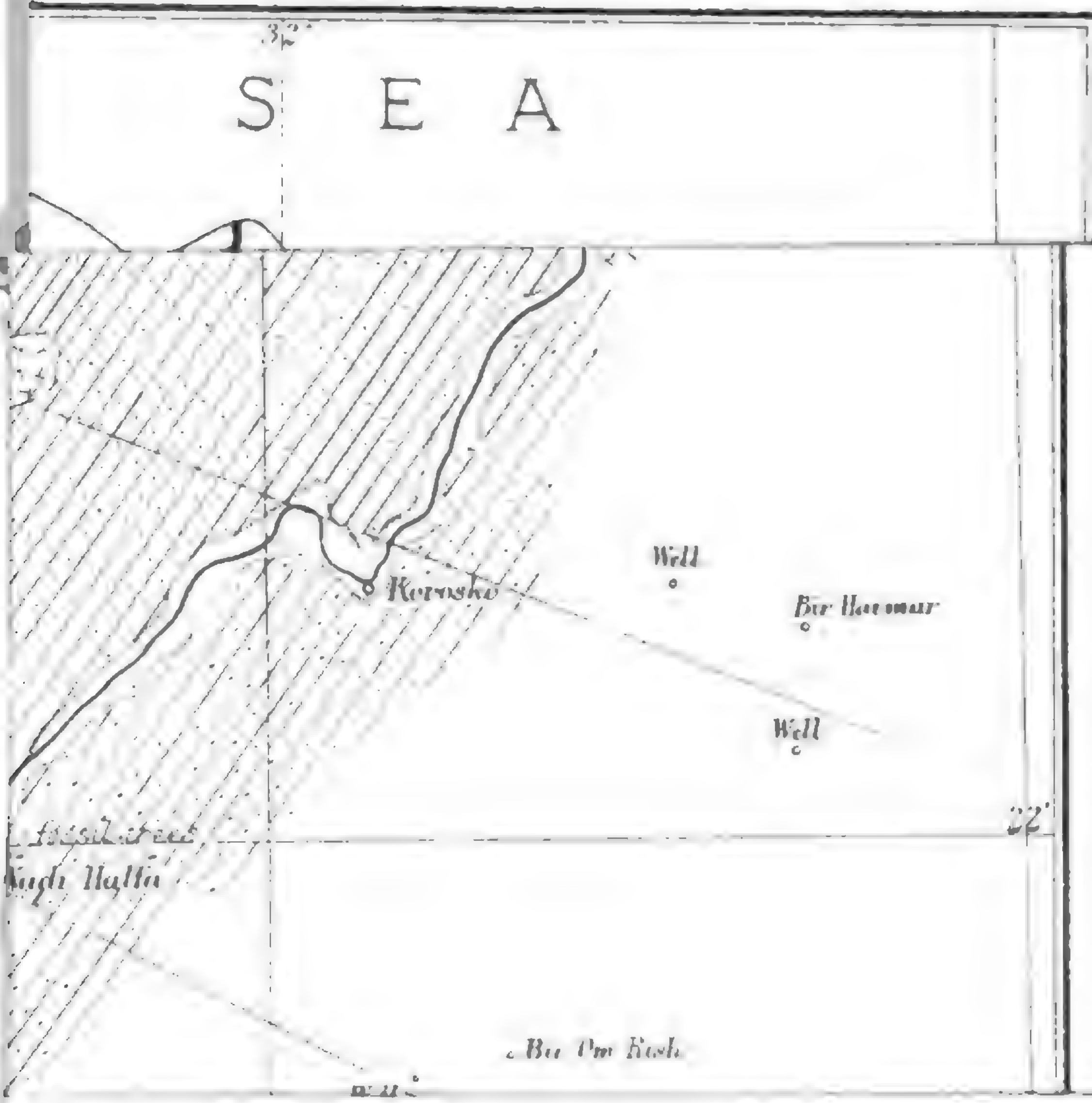
Geological Map of the Libyan Desert of Egypt, at the scale of $\frac{1}{3,000,000}$ = ·0211 inch to the mile, or about 50 miles to 1 inch.

Discussion.

The President congratulated the Author on the good use that he had made of his opportunities in carrying on geological observations in so very difficult a country as the Libyan Desert—a country so destitute of escarpments. The Author had made use of lines of wells when no other feature was available to guide him in predicting the underground lie of the rocks. From the evidences everywhere of æolian action, and the abundance of silicified and highly weathered tree-trunks, it appeared that this area must have been exposed to subaerial conditions through a vast period of time as an old land-surface. He hoped that Capt. Lyons would make further good use of his military travels in the Desert.

Mr. Hudleston congratulated the Society on at last receiving an interesting paper on the geology of the Egyptian Desert, where the general conclusions of well-known authors were confirmed and supplemented. He would like, amongst other matters, to have a possible explanation of a statement made here two years ago, that the Nubian Sandstone rested on basalt, but was invaded and metamorphosed by granite. The absence of the sandstone of Carboniferous age was not surprising in the level area, but when Capt. Lyons carried out his plan of investigating the Eastern Desert, it was not improbable that he would find this formation on the margin of the crystalline mountain-chain flanking the Red Sea. The silicification of large masses of wood was a feature characteristic of all the sandstone-beds of many ages in Egypt. Was this feature a contemporaneous one, or had there been a period of general silicification? The methods by which this had been effected were the result of replacement due to decomposition of woody tissue, and were observed in all parts of the world. The hydrographic questions raised by Capt. Lyons were of extreme interest and economic importance. He had received a good training in a sandy, thirsty district nearer home, namely, the Bagshots.

The Rev. G. Henslow remarked upon the great practical importance of Capt. Lyons's observations as to the Nubian Sandstone being a water-bearing stratum: thereby correcting the old view that oases were low-lying localities in which the water of the Nile, by penetrating soft strata, was accessible by wells. He observed that, by following the anticlinals to north-western localities, water might probably be found in the Western Desert, in places where it is at present unknown. He also drew attention to the evidence of earth-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quakes at Wadi Halfa, etc., as seen in the demolition of the temple at Karnak, and in vertical rifts on the face of perpendicular rocks, on which figures were sculptured that were now split completely down: Wadi Halfa being, as Capt. Lyons observed, in the direct line of the anticlinals, which extended in a slightly N.W. and S.E. direction.

Prof. Hull concurred with the view of the Author that the course of the Nile above Cairo had been determined by the line of fault, which follows the valley for many miles upward. As regards the age of the Nile in Egypt, he considered it as referable to the Miocene stage rather than to the Pliocene. The Miocene period in that part of the world was one in which the main features of the present land-areas received their general contours. Referring to an observation by Mr. Hudleston regarding the absence of Carboniferous beds in the Nile Valley, he reminded the Society that deposits of this age had been discovered by Dr. Schweinfurth in the Wadi-el-Arabah, between the Nile and the Gulf of Suez.

Dr. Irving could not resist the temptation to say a word to congratulate his old friend and former pupil on the excellent use he had made of the opportunities which his service in Egypt had put in his way, and on the interest of the results of his work now before the Society. Remarking on the silicification of wood, he wished again to emphasize the difference in the action of carbonic acid in petrological changes, according as it existed as a free acid or in combination with a base, as in sodium carbonate. The extent of the 'Natron' deposits pointed to the supply of alkaline waters over large areas in former times, holding the mineral in solution. The reaction of such waters upon the potash-felspar of the sands, furnished by the disintegration of the crystalline rocks, would not lead to the deposition of free silica (as in the ordinary process of kaolinization), because, while the potassium was taken up as a carbonate and carried away, the silica was also removed in solution, through combination with the sodium, to form sodium silicate. This last-named salt in solution would be readily decomposed by the organic acids and the carbonic acid furnished by decaying vegetable tissue, the silica being then deposited as a colloid *in situ*, and thus retaining the structural forms of the original tissue.

The Author, in replying, agreed with Mr. Hudleston as to the occurrence of Carboniferous beds underlying the Nubian Sandstone east of the Nile, but he had been unable so far to detect them in the Libyan Desert. The silicification of the fossil wood he believed to occur separately in each period, and were Egypt of to-day a wooded country, he would expect to find the same in progress in the Delta. He agreed with Prof. Hull that the north-and-south folds of Kharga were probably connected intimately with the Nile Valley fault. Dislocations fracturing inscriptions show movements to have taken place in historic times, as suggested by Mr. Henslow; and the water-system of the Desert, as determined by the folds of the strata, seems to indicate the position of oases other than those that we at present are acquainted with.

35. Notes *on the* Geology *of* South-eastern Africa. By David Draper, Esq., F.G.S. (Read May 23rd, 1894.)

[Plates XXII. & XXIII.]

Contents.

I. Introduction: Physical Features.

I purpose, in the following pages, to give a brief description of the principal physical and geological features of that portion of South Africa which is situated between the 26th and 31st degrees of south latitude and the 29th and 31st degrees of east longitude.

This area includes the Colony of Natal, the native States of Zululand and Swaziland, the south-eastern portion of the South African Republic (Transvaal), and the eastern portion of the Orange Free State and of Basutoland.

The leading physical features of this area are:—

(1) The Drakensberg Range.
(2) The 'Terrace,' lying along the foot of the Drakensberg.
(3) The Coast-belt, between the Terrace and the Indian Ocean.

(1) The Drakensberg Range.

This range of mountains is the continuation of the main range, which runs roughly parallel with the coast-line of Cape Colony, from west to east, and turns rather suddenly northward at the Natal boundary. It is known under various names in Cape Colony, and as the 'Drakensberg' where it forms the boundary of East Griqualand and the Colony of Natal.

The Drakensberg forms the watershed of the south-eastern portion of the continent; it divides the waters flowing westward into the Atlantic from those flowing eastward into the Indian Ocean. The rivers flowing westward, viz. the Orange and the Vaal, drain the inland portion of South Africa. Those flowing eastward, the principal of which are the Tugela, the Usuto, and the Pongolo, drain the coastal portion. These latter are small in comparison with the Vaal and Orange rivers.

The Drakensberg range consists of three distinct portions, differing greatly in aspect. (See Pl. XXII.)

(*a*) The *Mountain portion*, extending northward to the 'Mont-aux-Sources,' forming a bold and rugged mountain-chain, inaccessible except by means of a few obscure and dangerous

native footpaths, attaining an altitude of from 9000 to 10,000 feet, and culminating at the peak named by the French missionaries the 'Mont-aux-Sources,' about 11,000 feet high.

Several of the principal rivers of South Africa rise from this peak: the Orange and the Caledon, southern branch of the Vaal, flowing westward, and the Tugela flowing eastward.

(*b*) The *Hill-covered plateau*, extending from the Mont-aux-Sources northward to the Vaal River. This plateau is about 6000 feet above sea-level, and numerous hills, remains of a former range, are scattered about the surface. Several of these hills rise to an altitude of from 8000 to 9000 feet above sea-level.

(*c*) The *High-veld plateau*, extending from the Vaal River northward to the Klip Stapel and Lake Chrissie.

It consists of rolling plains, from 6000 to 8000 feet above sea-level, the highest eminence being the Klip Stapel, near Lake Chrissie. The northern branch of the Vaal River rises at this spot.

The High-veld plateau is devoid of hills; innumerable small lakes ('pans') are dotted about its surface, especially in the neighbourhood of Lake Chrissie.

Both the 'Hill-covered plateau' (*b*) and the 'High-veld plateau' (*c*) end abruptly eastward, but slope gradually westward.

The eastern termination of the plateaux forms the continuation of the Drakensberg range in Natal and in the South African Republic (Transvaal).

The whole of the Drakensberg range and the plateaux are devoid of timber; they are covered with short grass, forming admirable pasture-land for stock. The climate is healthy, though excessively cold in winter, snow falling frequently and covering the higher mountain-tops. Trees grow well where cultivated, especially the oak and several species of pine. Silicified trunks of trees are very numerous in parts of the High-veld plateau, especially near the town of Harrismith, Orange Free State. They are only found about 5000 feet above sea-level.

(2) The 'Terrace,' lying along the eastern foot of the Drakensberg. (See Pl. XXII.)

The average height of this terrace above sea-level is about 4000 feet, and it stretches for about 80 to 100 miles from the Drakensberg range towards the coast.

Numerous spurs of the main range and detached hills (outliers) have survived the general destruction of the great plateau, which, judging from these hills, must have extended beyond the limit of the terrace eastward. This terrace terminates somewhat abruptly towards the coast, where it forms an escarpment from 2000 to 3000 feet high, at the foot of which lies the Coast-belt.

The climate of the Terrace is healthy for man and beast; though the days are very warm in the summer months, the nights are cool and refreshing. The winter is mild, snow seldom falling.

Numerous rivers flow through this terrace from the Drakensberg, and in consequence it is deeply furrowed. Valleys, reaching down to the granite, have been cut out by these streams, especially on the edge of the Terrace eastward; some of these valleys are 80 miles in length, flanked by spurs of the Drakensberg, 3000 feet high above the valley-level.

Small forests are dotted over the surface of the Terrace, but upon the whole the country is devoid of timber, except along the edge of the Terrace, where some forests of indigenous pines are found growing in the more sheltered valleys.

(3) The 'Coast-belt,' lying between the Terrace and the Indian Ocean.

This belt is from 30 to 60 miles in width and continues all along the coast of Natal, Zululand, and Swaziland. It is generally low-lying and unhealthy, except along the Natal coast, where whites have resided ever since the occupation of the colony. (See Pl. XXII.)

The climate is sub-tropical, that is, extremely hot in summer, and temperate in winter.

Low rounded hills are the most prominent feature of the landscape, and along the shore sand-dunes and lagoons are frequently met with. Vegetation grows very luxuriantly, and the country is covered with dense bush.

II. Geological Features.

The principal groups of rocks which may be identified in the area under description are the following:—

Upper Karoo.	Volcanic rocks.	
	Cave-sandstone.	Probably Jurassic.
	Red Beds.	
	Molteno Beds.	
Lower Karoo.	Beaufort Beds.	Probably Triassic.
	Ecca Beds.	
	Dwyka Conglomerate.	Probably Permian.
Primary rocks.	Quartzite of the Gats Rand (in the Transvaal).	
	Malmani Limestone (dolomite).	
	[Bokkeveld Beds, wanting].	
	Table-mountain Sandstone.	
	Malmesbury Schists.	
Basement-rocks.	Gneiss and Granite.	

I have failed to discover some of the other South African groups, such as the quartzites of the Zuurberg[1] and the Zwarteberg, though I made search for them over a great portion of the country.

[1] [In the Transvaal this formation is represented by the quartzite of the Gats Rand.—T. R. J.]

I do not intend to enter into a minute description of the rocks composing the various groups in South-eastern Africa, but merely wish to place on record their mode of occurrence and the position they occupy.

(1) Volcanic Beds.

(Trap-amygdaloids.)

These occur only on the tops of the higher peaks of the Drakensberg, in the mountain-portion *a* (see p. 548). They form a most fantastic capping to the mountain-range, rising in peaks and pinnacles to 1000 feet in height above the sedimentary rocks of the range.

This group does not extend farther northward than the Mont-aux-Sources, and is rarely found lower than 8000 feet above sea-level. None of the higher eminences of the plateau or High-veld portion of the Drakensberg are capped with these rocks, which apparently never covered the sedimentary deposits northward of the Mont-aux-Sources. The Cave-sandstone forms the hill-tops of the plateau *b*. (Pl. XXII.)

(2) Cave-sandstone.

This group attains a thickness of between 500 and 700 feet, and is found underlying the volcanic beds, wherever they occur on the Drakensberg range.

It forms the crag-crowned tops of most of the hills situated on the plateau or *b*-portion of the Drakensberg, but does not extend northward of the Vaal River on to the High-veld plateau. If it ever was deposited there, it has been completely removed by denudation.

The specimens of *Semionotus capensis*, *Cleithrolepis Extoni*, and a new species of *Dictyopyge* (?) described by Mr. A. Smith Woodward (see Ann. & Mag. Nat. Hist. ser. 6, vol. xii. 1893, p. 393, pl. xvii. fig. 1), have been found in the Cave-sandstone in the neighbourhood of the villages of Ficksburg and Rouxville, in the Orange Free State.

(3) Red Beds.

This group occupies a small area in the vicinity of the town of Harrismith (O.F.S.), and is exposed in the lower portion of the Plat-Berg, on the town-commonage, extending southward into 'Vitsies' Hoek, towards the Mont-aux-Sources.

It is about 100 feet thick at the section near Harrismith, and contains a bed of bone-breccia, principally composed of reptilian remains. Specimens from this bed were sent to the Royal College of Surgeons by Messrs. Orpen, and noticed by Prof. Huxley in the Society's Quarterly Journal, vol. xxiii. (1867) p. 5, having been previously described by Prof. Owen in his Catalogue of the Fossil Reptilia in the Museum of that College (1854).

Northward, towards the Vaal River, the Red Beds do not appear to exist, but seem to be replaced by a dark-coloured, gritty sandstone, containing worn crystals of felspar, of considerable size and rounded

quartz-pebbles about the size of pigeons' eggs. The dark colour of the rock is caused by the quantity of manganese oxide, which occurs in small veins and beds in the rock, and generally completely envelopes the quartz-pebbles.

Silicified remains of trees are abundant in the upper portion of the Red Beds and in the dark-coloured grit.[1] In many cases the lower portion of the trunk is found standing erect, on the spot where the tree originally grew. Some of these trees were of considerable size, judging from their silicified remains, which measure over 4 feet in diameter in occasional specimens.

(4) Molteno Beds.

This extremely important series occupies a large area in South-eastern Africa.

The High-veld plateau of the Drakensberg (*c*), and nearly the whole portion of the Terrace, lying north of the Tugela River,[2] is composed of this series, which is the coal-bearing formation of South Africa, and contains the only workable coal-seams yet discovered there. Prof. A. H. Green has very ably described the Molteno Beds as he found them in Cape Colony,[3] and his description applies generally to the series wherever it occurs in South Africa.

There are a few points of difference, however, between the Molteno Beds of Cape Colony and the same strata in South-eastern Africa, the principal of which are (1stly) the absence of boulders, which Prof. A. H. Green noticed as occurring in the Molteno Beds in Cape Colony. These I have never found anywhere in Natal or in Zululand, in the districts where the Molteno Beds are most exposed to view, and where admirable sections can be obtained. (2ndly) The superiority of the coal over that of Cape Colony. Some of the coal-seams of the Transvaal and Natal are only slightly inferior to ordinary English coal, and are now taking the place of the imported article for all engine work.

The coal-beds are contained in the lower 500 feet of the series, which consists principally of false-bedded gritty sandstones, with inferior beds of shale, generally overlying the coal-seams, which rest on gritty sandstone.

The upper portion of the Molteno Beds consists of grey and dark coloured shales, interstratified with small bands of sandstone.

The most prominent feature of the Molteno Beds along the eastern flank of the Drakensberg is a thick columnar dolerite, which lies between the Molteno Beds and the 'Red Beds,' and forms a crag along the mountain-side, about 200 feet high, and extending for over 100 miles.

[1] [Described by G. W. Stow, F.G.S., in his Reports on the Geology of the Orange Free State, 1878 & 1879.—T. R. J.]

[2] This portion of the country, including Zululand, has not yet been geologically mapped.

[3] See Quart. Journ. Geol. Soc. vol. xliv. (1888) p. 248.

The Molteno Beds on the High-veld plateau (*c*) are composed almost entirely of sandstone; there the upper, shaly portion of the series is wanting.

The coal occurs at a much greater altitude than that of the Terrace. Near Lake Chrissie a coal-seam crops out about 6000 feet above sea-level, while the coal of Natal and Zululand is only about 4000 feet. This would lead to the supposition that a great fault intervenes; and in all probability that is the case, though the exact locality of the fault has not yet been traced.

The Molteno Beds thicken northward towards the Transvaal; from 1000 feet in the Drakensberg near Pietermaritzburg, Natal, to 2000 feet at Newcastle in the same colony. The best coal discovered on the Terrace is in the Division of Dundee, in the northern portion of Natal.[1]

Small patches of Molteno Beds occur along the coast-line of Natal and Zululand. These dip seaward at an angle of about 20°, while the same series inland lies approximately horizontal.

These Molteno Beds of the coast, which occur at sea-level, are 4000 feet lower than the lowest inland beds, having been displaced by a great downthrow, traceable by a distinct line of faulting in the immediate neighbourhood. A large bed of good anthracite has recently been discovered near St. Lucia Bay on the east coast.

(5) Beaufort or Karoo Beds.

Unfortunately for the student of South African geology, no uniform classification of the South African rock-systems has been decided upon. Names have been given to the strata, to suit the views of the observer who has described or identified them. Sometimes the same division is known under two or three different names; and a great deal of confusion is the result.

Looking through Prof. Green's communication to this Society, Quart. Journ. Geol. Soc. vol. xliv. (1888), I find he has omitted the 'Beaufort Beds' from his classification, and substituted 'Karoo Beds' and 'Kimberley Shales.' The latter I have failed to identify in South-eastern Africa; but the Karoo Beds, as described by him at p. 261 *op. cit.*, occur, and are exposed on the edge of the Terrace, forming crags along the sides of the hills. The characteristic spheroidal weathering is very marked, and consequently these crags are readily mistaken for flat igneous sheets, to which they bear a close resemblance, when viewed from a distance.

The coarse gritty sandstones of the Molteno Beds pass gradually downward into finer-grained, laminated, arenaceous shales, and then into the buff-coloured, fine-grained sandstones which compose these Beaufort or Karoo Beds.

Weathering brings out the spheroidal structure of this rock; the separate masses, when broken up, showing concentric circles of differently coloured sandstone. Though the Karoo Beds are apparently 200 or 300 feet thick in the southern portion of the Terrace,

[1] See F. W. North's Report on the Coalfields of Natal, Dept. of Mines, 1881.

especially near Pietermaritzburg, they die away completely northward, and disappear before reaching the Pongolo River. About 10 miles south of the Pongolo, they occur underlying the Doembe Mountain, but are only about 50 feet thick at that place. I failed to find any trace of this series north of the Pongolo.

(6) Ecca Beds.

Apparently this group is identical with the 'Pietermaritzburg Shales' of Dr. Sutherland.

A most characteristic section occurs near the town of Pietermaritzburg, where the beds are more than 2000 feet thick; and the whole of Natal westward of this town, up to the Klip River, besides a large portion of Zululand, is composed of these Ecca Beds. They thin out rapidly northward, disappearing near the Pongolo River; and they do not reappear in Swaziland, lying to the north.

The Ecca Beds consist principally of dark-coloured shales and fine-grained sandstones. I could not trace any signs of contortion in them along their eastern outcrop; and I feel little doubt that it is conformable to the underlying 'Dwyka Conglomerate.'

(7) Dwyka Conglomerate.

('Glacial Boulder-clay' of Dr. Sutherland.)

Some exceedingly fine sections of 'Dwyka Conglomerate' are exposed in the deeper gorges of the Terrace, where crags of this rock occur, over 700 feet in height, showing distinct lines of stratification and unmistakable evidence of the aqueous deposition of the material constituting this rock.

The characteristics of the conglomerate noticed by Mr. E. J. Dunn and Prof. A. H. Green, and so well described by them as occurring in Cape Colony, are equally distinct in South-eastern Africa, and a description of this rock in one part of the country will answer for any other part.

But I have failed to find any signs of contortion or crumpling of this series along its eastern outcrop, where it is found lying horizontal. Nearer to the coast, however, it has been disturbed, together with all the overlying strata, by the great fault occurring there, and is consequently found dipping seaward, outside of the line of faulting, and considerably lower than on the inner side of the fault.

I have not yet succeeded in finding any traces of ice-scratching or grooving in this series, or on the boulders contained in the body of the rock; but ripple-marking is frequently met with, and the whole appearance of the rock suggests the action of water. A small patch of horizontal Dwyka Conglomerate containing very few pebbles or boulders, but very much ripple-marked, occurs on the coast-belt in Zululand and Swaziland, about 800 feet above sea-level, and at least 1000 feet lower than the main body of the conglomerate along the flank of the Terrace.

The Dwyka Conglomerate continues in one unbroken line, from St. John's River, through Pondoland and Natal, to the Umkuze River in Zululand; it thins rapidly towards Swaziland; and near the Pongolo River it dies away completely, disappearing at about the same spot as the Ecca and Karoo Beds.

The largest mass of foreign rock that I have found embedded in the Dwyka Conglomerate was a boulder of granite, 9 feet long by 4 feet wide, and protruding 3 feet above the matrix; I do not know how deep the boulder extended into it. In common with all the other (smaller) boulders this was rounded at the angles, and showed conspicuous signs of having been submitted to severe aqueous action; but I could find no signs of any ice-action, either at this or any other spot. I noticed one feature in the Dwyka Conglomerate in South-eastern Africa which I have not seen hitherto mentioned, and that was the occurrence of great intrusions and flat sheets of igneous rock (dolerite), the latter either over- or underlying the conglomerate, and sometimes both above and below.

The controversy about the origin of the matrix of the Dwyka Conglomerate has not, I believe, so far been definitely decided; and there appears to be as much evidence in favour of the igneous as of the aqueous theory of the origin of the bulk of the rock.

Dr. G. A. F. Molengraaf, Professor of Geology in the University of Amsterdam, who has studied the rock both *in situ* and by means of microscopic sections, expressed the following opinion of the origin of the rock, in a letter to me, dated January 20th, 1892:—

"The Dwyka Conglomerate gives me the impression of a volcanic tuff (I mean a probably Permian diabase-tuff), full of fragments of older rocks. Such tuffs are not so very rare, even in diabases and basalts themselves; the amount of the different included rock-fragments may surpass that of the rock itself."

The masses of rounded rock and the numerous boulders and pebble-beds contained in the Dwyka Conglomerate certainly point to the fragments of other rocks contained therein having been submitted to the action of the ocean along a coast-line: but might not the material of the matrix here have been principally supplied from some volcanic region now buried beneath a great mass of sedimentary strata?

So far all the strata dealt with have been approximately horizontal, and no signs of unconformity exist inland. On the coast, what there is of these beds, existing only in small isolated patches along the sea-shore, is found to be dipping seaward; a line of hills, consisting principally of granite and Primary rocks, intervenes between this series on the coast and the same rocks inland.

The Primary Rocks consist principally of:

(8) Table-mountain Sandstone.

This is found along the higher portions of the Bothas Hill range, near Durban, where it lies horizontal and in small patches: and in Zululand, principally near Ulundi. At this latter spot the series

contains several beds of gold-bearing conglomerate, practically identical with the gold-bearing conglomerates of Johannesburg.

These Zululand conglomerates are being worked for gold, and will in all probability yield good returns.

I have found no trace of the quartzites mentioned by previous writers as overlying the Table-mountain Sandstone in Cape Colony. If these quartzites do occur in South-eastern Africa, they have not yet been recognized by anyone who has examined the strata in this region.[1]

The Table-mountain Sandstone rests unconformably upon the underlying schists.

(9) Malmesbury Schists.

This series, which consists of schists, slates, shales, and small beds of quartzite, tilted to a very high angle, and very much contorted and crumpled, is found principally flanking the granite hills along the coast-line and in the deeper valleys of the Tugela, Pongolo, Umkuze, and other rivers. It occupies a large area in Swaziland and Northern Zululand.

Gneiss and granite are exposed in the deeper valleys; and occasionally, as at Bothas Hill, near Durban, they make small eminences.

The weathering of the Primary rocks, generally into small rounded hills, with narrow and precipitous valleys between, shows a marked contrast with the crag-crowned hills and broad valleys of all the later sedimentary series.

The Malmesbury Schists (Dunn) are identical with the 'Swazi Schists' of Dr. Schenck, and the Lydenburg Schists and Namaqualand Schists of Mr. E. J. Dunn.

III. Conclusion.

From the foregoing brief description of the occurrence of the rocks in South-eastern Africa several considerations arise, which are likely to disturb the theories of the earlier geologists with regard to certain phenomena which they imagined had taken place during the deposition of the sedimentary rocks of the southern portion of the continent.

The theory of the late Mr. A. G. Bain, subsequently endorsed by Mr. E. J. Dunn, as to the supposed great central lake-basin of the Karoo, can scarcely be maintained in face of the fact that the Molteno Beds occur on the east coast, dipping seaward into the Indian Ocean, and at a level 4000 feet below their occurrence inland. This denotes the extension of the Molteno Beds far beyond the limits of the continent as at present outlined.

No doubt the Molteno Beds covered a far greater area in all directions before the great fault occurred, which lowered them along the coast-line, and which, in all probability, defined the shores

[1] [The quartzites of the Gats Rand may be equivalent.—T. R. J.]

of the continent as at present existing. Consequently the shores of any lake in which such a vast deposit of sedimentary material (comprising the Ecca, Karoo, and Molteno Beds) could have been accumulated must have extended far beyond the present boundaries of the continent, and could scarcely be called a 'central lake-basin of the Karoo,' for this would lead one to believe that its area was limited by what is geographically called 'the Karoo.'

The differences of thickness observed in the Dwyka Conglomerate, Ecca, Karoo, and Molteno Beds lead us to suppose that great oscillations of the surface occurred during their deposition.

The Dwyka Conglomerate, Ecca and Beaufort Beds thin out rapidly northward, and die away completely near the Pongolo River, although they attain a thickness of over 700 feet 50 miles away towards the south; the Ecca and Beaufort Beds also thicken southward. On the other hand, the Molteno Beds thicken in the contrary direction, thinning rapidly southward.

Apparently, during the deposition of the Dwyka, Ecca, and Beaufort Beds, dry land existed in the central portion of South Africa, notably at what is now the great northern watershed of the Witwatersrand, and the high-lying portions of the High-veld plateau, and extended southward to the present boundaries of Natal.

This dry land consisted of granite and Primary rocks. The Dwyka, Ecca, and Beaufort Beds are seen to die out against these rocks wherever they are found in South-eastern Africa. On the other hand, the Molteno Beds overlie the highest eminences of Primary rocks and granite, even to the top of the Klip Stapel near Lake Chrissie, 7000 feet above sea-level.

The non-existence of the Cave-sandstone and the volcanic beds north of Natal and Basutoland respectively can scarcely be taken as definite evidence that they never were deposited there. The vast amount of denudation which has occurred on a territory that has not been submerged since the close of the Jurassic period will account for the removal of immense bodies of rock. At the same time the Cave-sandstone is by no means so important a formation north of the town of Harrismith as it is southward; and there are evidences of a thinning of this series northward.

In the south-eastern portion of South Africa I have failed to find the evidences of disturbance in the Ecca and Dwyka Beds described by Prof. A. H. Green in Cape Colony. The only great unconformity that I could discover was between the Malmesbury Schists and the Table-mountain Sandstone. The former are tilted and highly contorted, occasionally being quite perpendicular; the latter lies horizontally upon their upturned edges; the Dwyka Conglomerate, and all the overlying sedimentary deposits, follow conformably one to the other. As previously mentioned, all the strata lying horizontally in the inland area dip rapidly seaward when observed near the coast, in consequence of the great fault along the coast-line.

There is a marked distinction between the material composing the Dwyka Conglomerate and the Ecca Beds immediately overlying it, and consequently the junction of these two series is easily

defined; but to distinguish the Ecca from the Beaufort Beds and from the upper series is by no means an easy task.

They all graduate one into the other, so that the line of demarcation in many cases cannot be determined with any degree of certainty. Fossil evidence is very scarce, except leaf-impressions, principally of *Glossopteris*. These are found in the Molteno, Beaufort, and Ecca Beds. No fossils have been found in the Dwyka Conglomerate in any part of South Africa up to the present date.

The 'Red Beds' yield an abundant supply of fossil reptilian remains, and the Cave-sandstones yield specimens of fish. A portion of a fish was discovered by the writer in the Molteno Beds of Natal, and is, I believe, the first specimen discovered in this series; unfortunately, it is too fragmental for classification. Mr. A. Smith-Woodward has described it in the Ann. & Mag. Nat. Hist. ser. 6, vol. xii. 1893, p. 397, pl. xvii. fig. 4.

Evidences of recent glacial action are entirely wanting; but Dr. Sutherland has noted ice-scratchings, etc., on the surface of the rocks underlying the Dwyka Conglomerate at Durban, and possibly ice may have played some part in the creation of the Dwyka Conglomerate. Ice is looked upon as the principal agent in the removal of so vast a quantity of the sedimentary strata as that now missing in South Africa by those who are in favour of a 'glacial period' having extended over the earth at some time of its existence; but the total absence of moraines, erratics, and other evidences of glacial action must be accepted (as against vague theories) in support of the arguments which tell against the glaciation of the southern portion of the continent since the close of the Jurassic period.

I cannot imagine glaciers descending from the peaks of volcanic rock without bearing boulders of the characteristic rock of that series, and these would be deposited in the lower-lying valleys. The absence of such boulders is strong evidence against any such glacial theory. On the other hand, the softness of the rocks of the horizontal strata, and the great amount of weathering to which they have been subjected, in a climate with so variable a temperature as the south-eastern portion of the continent possesses, would account for the non-existence of any ice-scratches or markings.

The numerous 'pans' that are found all over South Africa have been advanced as evidence of glacial action; but here, again, other evidence is entirely wanting. 'Pans' exist in South Africa at all elevations, and in rocks of all geological periods—on plains, in valleys, on the High-veld plateau, and on mountain-tops; in fact, almost every flat-topped hill in South Africa has a 'pan' or small lake on the top of it. They appear to be the result of the disintegration and dissolution, by chemical means, of the rock-forming constituents of the strata.

Various products from the rocks in the neighbourhood are generally found on the lower (or outlet) side of these pans—limonite, kaolin, and clay-beds, derived from the destruction of the igneous

rocks, which generally exist near these pans; but there are no signs of any rounded pebbles, nor any moraine-material, such as would denote the previous glaciation of the area in which they occur.

IV. Supplemental Notes on the Dwyka Conglomerate.

Before closing this paper I wish to place on record a few facts with regard to the Dwyka Conglomerate, which will perhaps tend towards proving that it is *not* a glacial deposit, similar to the Boulder-clay of Europe and America.

1stly. It is undoubtedly stratified.

The following is a section observed by me at the farm 'Alpha,' about 12 miles east of the town of Vryheid (Zululand):—

Molteno Beds at the top.
Beaufort Beds. } 130 feet.
Ecca Beds.
—Distinct line of division.—

		Feet.	
Dwyka Conglomerate.	Shaly. Fragments isolated and few	4	138 feet.
	Hard Rock. Fragments large and numerous	10	
	Hard Rock. Stratified; fragments in layers	20	
	Hard Rock. Stratified; without fragments	4	
	Grey Shaly Rock. Fragments numerous	3	
	Grey Indurated Shale. No fragments	5	
	Grey Indurated Shale. Fragments numerous and of medium size	6	
	Blue Laminated Shale. No fragments	40	
	Blue Indurated Rock. Fragments large and numerous	10	
	Blue Indurated Rock. Numerous small fragments in lines and layers	20	
	Grey Shale with wavy laminations. Without fragments.	6	
	Blue Hard Rock. Fragments numerous and of medium size	10	
	Blue Hard Rock. Fragments clustered together, and of medium size: thickness undetermined.		

This section scarcely conveys the impression of a Boulder-clay. The fragments of older rocks included in the Dwyka Conglomerate consist principally of granitic rocks, also quartzites, shales, schists, and other rocks derived from the Malmesbury and Basement series, and numerous fragments of conglomerate ('banket')—similar to that now being worked for gold at Johannesburg, derived from the Table-mountain series. The fragments are all more or less rounded, but rarely quite round or oval in shape. As previously mentioned, I failed to find any trace of ice-scratching on any of the fragments of older rock in the Dwyka Conglomerate.

2ndly. The Dwyka Conglomerate thins out rapidly northward against the older rocks. If it had been a glacial deposit derived from the high land of the central portion of South Africa, the deposit would have been thickest near that part of the mountains from which it descended. The contrary is the case, however; it thickens away from them.

3rdly. The general horizontality of the beds is evidence against any glacial theory.

4thly and finally. The matrix, when microscopically examined,

shows in a marked manner the characteristics of a volcanic ash (see above, p. 555); and when the matrix is reduced to powder, and pressed into clay, it does not show the sticky, plastic nature of a glacial clay, but is sandy and friable.

Note.—In the section just described, each distinct layer was seen to be separated from the one next above by a clear line of division.

EXPLANATION OF PLATES XXII. & XXIII.

Plate XXII.

Fig. 1. Diagrammatic section of the Drakensberg and the High-veld plateau. (Approximate distance = 390 miles.) This shows the sedimentary deposits lying horizontally in relation to the igneous and Primary rocks. The Dwyka, Ecca, and Beaufort Beds are seen to thin out northward, while the Molteno Beds thicken in the same direction. The Primary and Basement-rocks underlying the Dwyka Conglomerate are in all probability continuous from the coast to the Klip Stapel and beyond, as they appear in all the deeper valleys on the eastern flank of the Drakensberg. At Lang's Neck the coal-seam in the Molteno Beds suddenly drops from 5600 to 4000 feet above sea-level, a drop which no doubt indicates a considerable fault.

Fig. 2. Diagrammatic section from the Mont-aux-Sources on the Drakensberg to St. Lucia Bay, on the East Coast. (Approximate distance = 220 miles.)

Plate XXIII.

Section from Hartebeest-Fontein in the Transvaal to Vredefort in the Orange Free State, partly based on Dr. Molengraaf's researches. (Approximate distance = 50 miles.) The lower portion of the sandstone (A) includes beds of boulders, consisting principally of masses of gold-bearing conglomerate. The breccia (B) consists chiefly of irregular fragments of shale, quartzite, and sandstone, similar to Nos. 1, 2, and 3; and it denotes the existence of a great fault, and downward displacement and disappearance of the strata between the granite and the dolomite. The Table-mountain Sandstone contains auriferous conglomerates in its middle portion as well as in the upper ('Black Reef') series: and the pebbles are larger in the former than in either the upper or lower beds. The section at De-Wette Drift, Vaal River, about 12 miles south of Potchefstroom, is conclusive as to the position of the dolomite with respect to the overlying and underlying rocks, which are nearly vertical at this point, and clearly exposed in the river-bed.

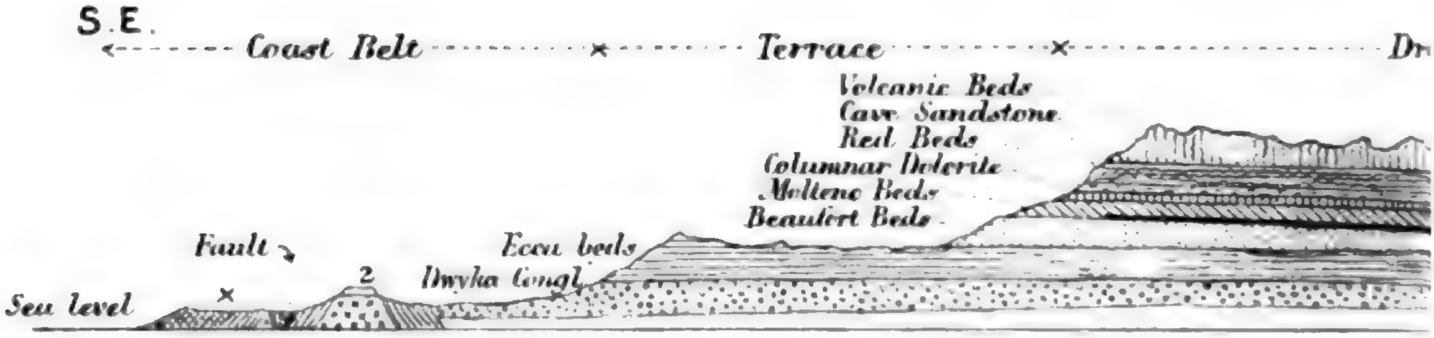
[For the Discussion on this paper, see p. 564.]

Fig. 1.

DIAGRAMMATIC

SECTION OF DRAKENSBERG AND

ABOUT 390 MILES



x. Molteno & other beds

2. Table Mountain San

The dark lines in the Molteno beds indic

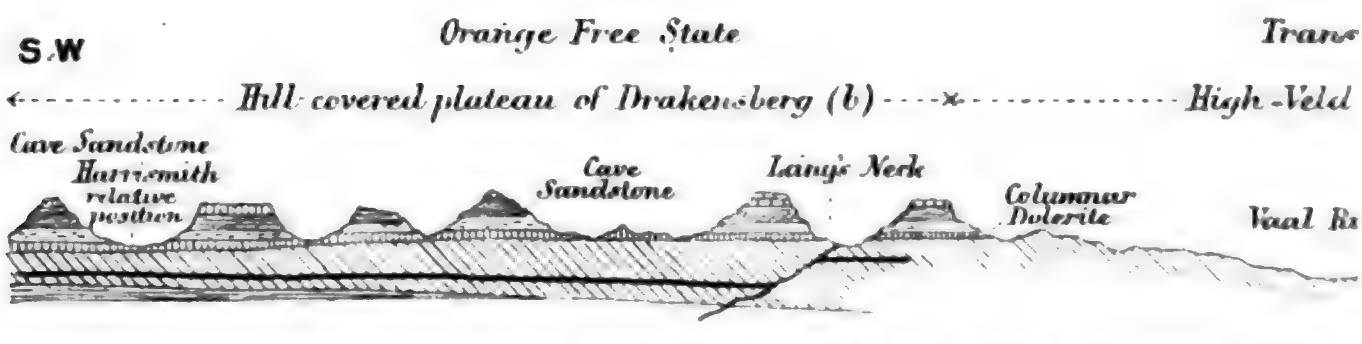


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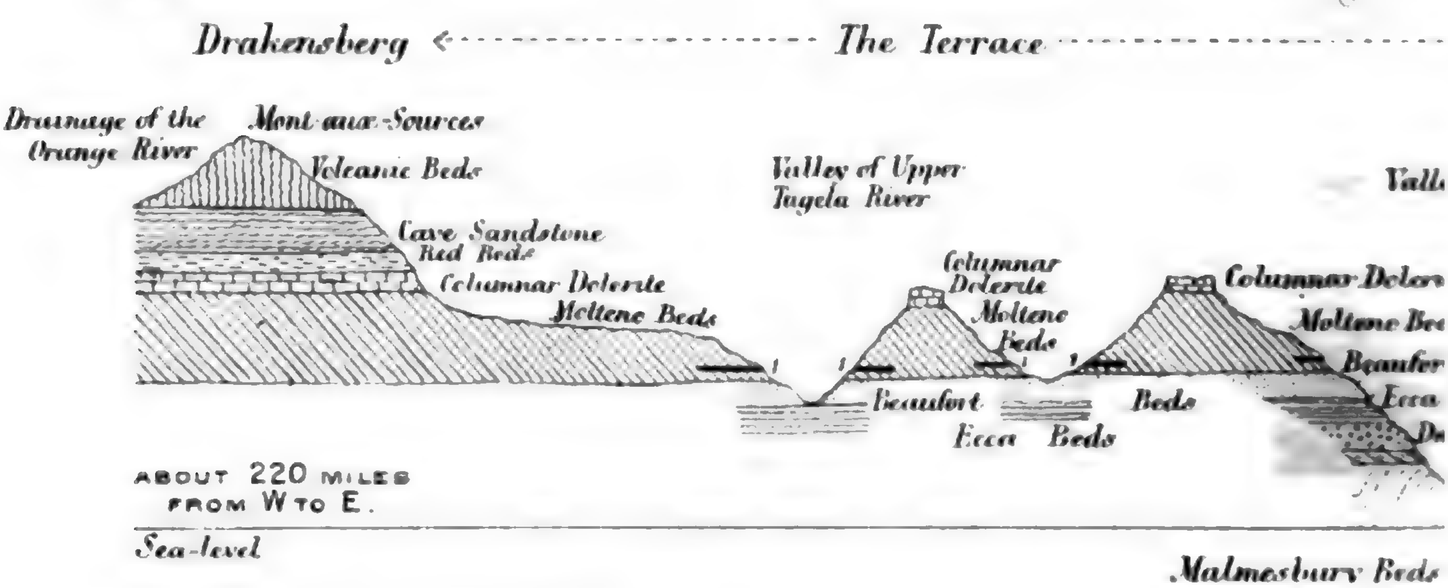
Fig. 2.

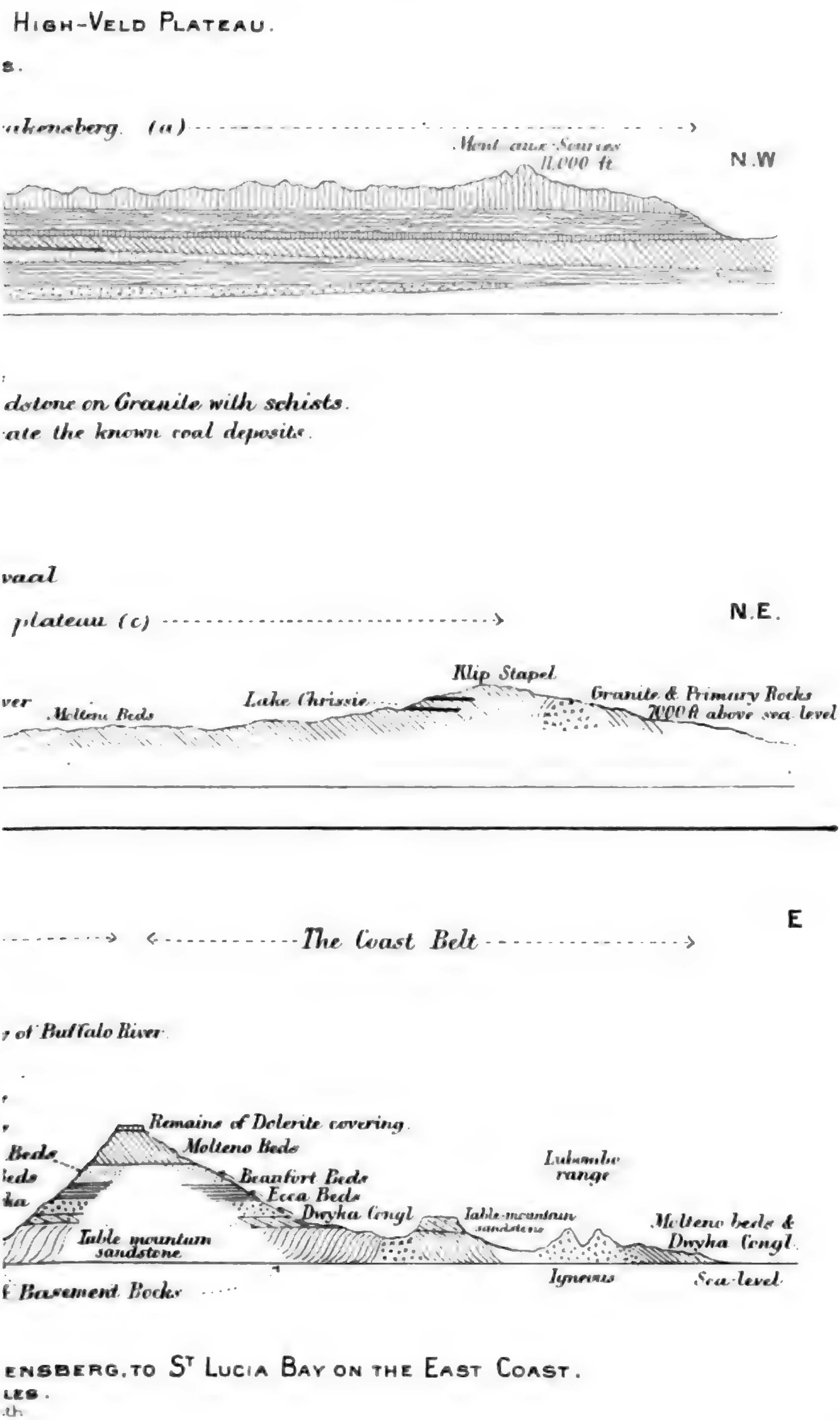


1,1,1,1. Coal seams in Molteno Beds.

DIAGRAMMATIC SECTION FROM THE MONT-AUX-SOURCES, DRA

ABOUT 220 M

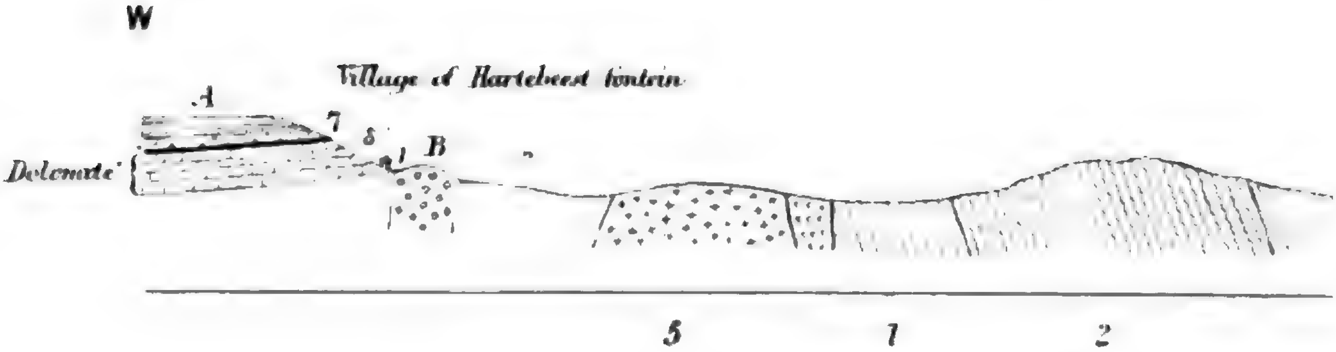
D. Draper del. Mintern Bros.


High-Veld Plateau.
s.
akensberg (a)
Mont aux Sources 11,000 ft
N.W
dstone on Granite with schists.
ate the known coal deposits.
vaal
plateau (c)
N.E.
ver
Molteno Beds
Lake Chrissie
Klip Stapel
Granite & Primary Rocks 7000 ft above sea level
E
The Coast Belt
of Buffalo River
Remains of Dolerite covering.
Molteno Beds
Beds
Beaufort Beds
Ecca Beds
Dwyka Congl.
Table mountain sandstone
Lubombo range
Table mountain sandstone
Molteno beds & Dwyka Congl.
Igneous
Sea level
Basement Rocks
ensberg, to St Lucia Bay on the East Coast.

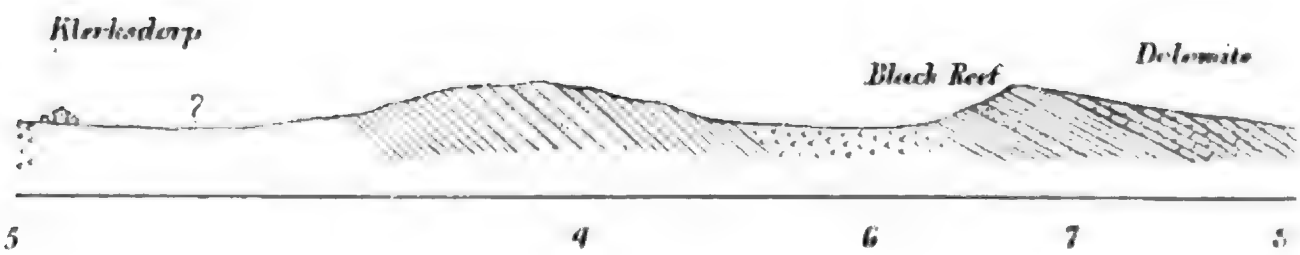
SECTION OF THE STRATA FROM HARTEBEEST-FONTEIN

ABOUT 50 M

(PARTLY BASED ON

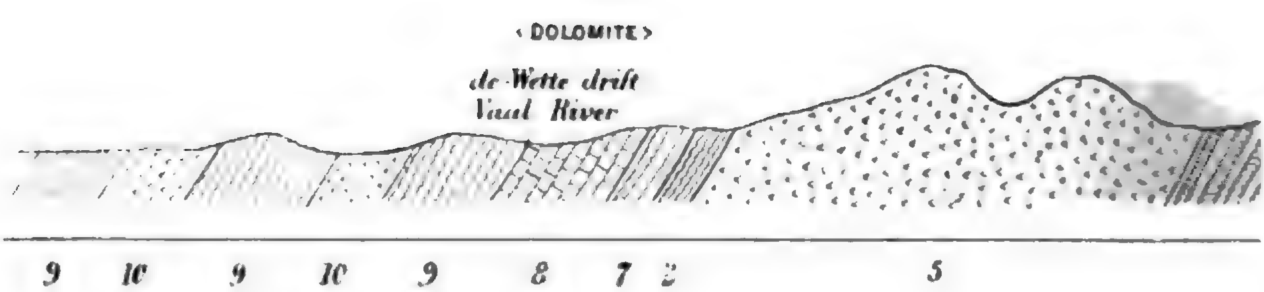


A. Sandstone, gritty.
1. Gneiss & Schi
2. Malmesbury Be
3. Lower Portion
4. Table-mountai
5. Igneous Rocks.
6. Amygdaloidal



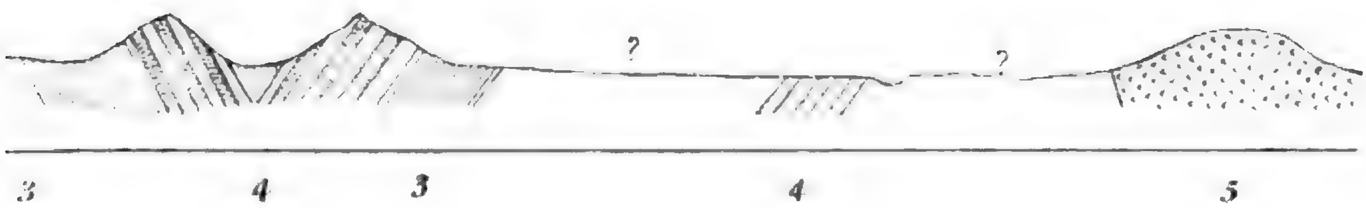
7. Upper Series of the Table-mountain
8. Dolomite = "Oliphant-Klip or "Elepha
9. Red Shale & Quartzite = Quartzite
10. Intercalated Igneous Rocks.
11. Grey Shale

5. Granite



D. Draper del.

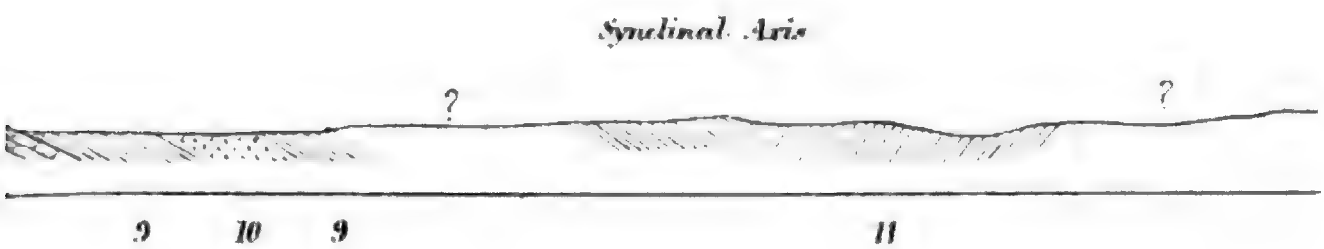
N THE TRANSVAAL TO VREDEFORT IN THE ORANGE FREE STATE.
ES FROM WEST TO EAST.
R MOLENGRAAF'S RESEARCHES.)



urk-coloured. B. Breccia.

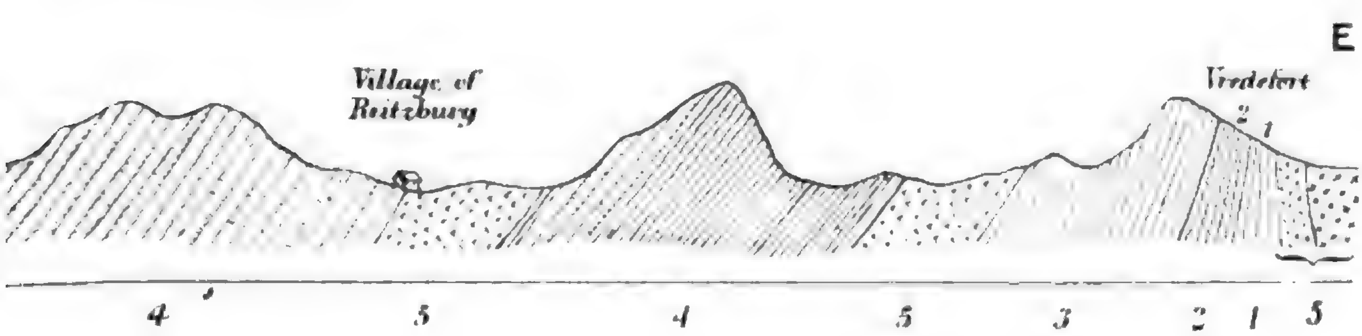
Table-mountain Sandstone.
Sandstone

reenstone, Intercalated bed



Sandstone (Auriferous) known as the "Black Reef"
t Rock"
of the Zuurberg, Zwarteberg, &c.

5. Greenstone.



ers. Bros. lith.

36. *The* Occurrence *of* Dolomite *in* South Africa.

By David Draper, Esq., F.G.S. (Read May 23rd, 1894.)

[Plate XXIII.]

Mr. W. H. Penning, F.G.S., examined a certain rock near Lydenburg, when in company with Mr. A. C. Crutwell, and they described it in the Quart. Journ. Geol. Soc. vol. xli. (1885) p. 576, as "a peculiar blue, fine-grained, calcareo-siliceous rock." This they named "'chalcedolite,' in consequence of the chalcedonic texture frequently displayed—indeed, some portions of the rock are true chalcedony. . . Sometimes it occurs in amorphous masses, weathered to a grey colour, and to a peculiar, rough, trachyte-like surface; but mostly in thin beds, 2 or 3 inches in thickness, with earthy partings."

Mr. Penning in another contribution, Quart. Journ. Geol. Soc. vol. xlvii. (1891) p. 456, mentions the same rock (chalcedolite) as immediately overlying the 'Black Reef series' of what he calls the Megaliesberg Beds.'

Mr. C. J. Alford, F.G.S., in his 'Geological Features of the Transvaal,' 1891, mentions the occurrence and peculiarities of this rock as follows:—

Page 3. Referring to 'alluvial deposits,' he states:—"In several places deposits of a fairly pure crystalline *carbonate of lime* are met with, those in the vicinity of the Six-mile Spruit, between Pretoria and Johannesburg, being some of the most remarkable; these appear to result from the disintegration of a hard blue quartzite plentifully veined with lime, which occurs in the neighbourhood."

Page 6. "The metamorphism of these beds ['schistose rocks'], where in contact with, or adjacent to, the irruptive rocks, results in several somewhat complicated products; amongst others the calcareous quartzite before mentioned, which in some places passes into dolomite, and on exposure to atmospheric influence yields up its lime and becomes, on the surface, altered into a species of chert. This calcareous quartzite is locally known as *elephant-rock*, from the resemblance which its weathered surface bears to the hide of that animal. In other places, as on the hill near the junction of the Olifants and Blyde rivers, it has resulted in very calcareous beds of granular quartzite, bearing in structure a marked resemblance to dolomite, in some of which the siliceous and calcareous matter has assumed a peculiar banded arrangement."

And finally, at p. 25:—"In the neighbourhood of Wonderfontein and in other places, the erosion of the exposed surface of the altered sandstone has produced very peculiarly weathered rock-masses, and the underground watercourses have resulted in the formation of many a series of extensive caves, the tortuous windings of which can be followed for a long distance, and which form the underground

course of the Mooi River. In the calcareous quartzite before alluded to the river has, in course of time, worn for itself a subterranean course by dissolving out, in the first instance, the little veins of calcite, and then, when increasing volume gave it greater strength, the quartzite also, the lime being again deposited as stalactitic formations in the caves. . . . . Some parts of these quartzite beds are sufficiently calcareous to produce on calcination a valuable lime."

From these extracts from their writings it will be seen that both Mr. Penning and Mr. Alford have described this rock from the peculiarities that they have noticed where they examined it *in situ*. Mr. Penning named it 'chalcedolite, in consequence of the chalcedonic character frequently displayed.' Mr. Alford calls it a 'calcareous quartzite,' passing into dolomite, and superficially 'altered into a species of chert.'

Having had especial opportunities of examining this rock, especially several deep workings in it in the Malmani district, I have come to the conclusion :—

1stly. That the 'elephant-rock' occurring in various parts of the Transvaal, but principally in the Potchefstroom, Lichtenburg, Malmani, and Lydenburg districts, is really a dolomite, with thin interstratified siliceous bands, for the following reasons :—

(*a*) Its composition is

48 per cent. carbonate of lime,
48 per cent. carbonate of magnesia,
4 per cent. silica.

(*b*) That the residue, after the limestone has been removed by the atmosphere, is a dirty-brown, soft, earthy matter similar to manganese oxide. This occurs in all the caves, and in between the siliceous layers, where it has been long exposed to the weather.

(*c*) That the bulk of the rock is of the composition previously mentioned (*a*), the bands of siliceous material being not more than 10 or 15 per cent. of the whole mass where it has not suffered from atmospheric influences. That the 'débris' from the rock consists largely of fragments of the siliceous bands, strewn about on the surface, I admit; but this only occurs *on the surface*, and is the result of a large amount of the calcareous portion of the rock having been removed.

I submit that the alteration of a 'calcareous quartzite into a 'dolomite,' and this again into a 'species of chert,' is, to say the least of it, unique.

2ndly. That this rock is interstratified between the Table-mountain series (in which the conglomerate-beds of the Transvaal are situated) and the quartzites of the Gats Rand (the 'quartzites of the Zuurberg' of Bain); and in proof of this assertion I submit a section (Pl. XXIII.) taken by Dr. G. A. F. Molengraaf, Professor of Geology in the University of Amsterdam, and myself, from Hartebeest-Fontein

to Vredefort. This section shows the 'dolomite' in its true position with regard to the other rocks. A section from Pretoria to Vredefort (south) would show a similar occurrence of the several strata.

In 'Petermann's Mittheilungen,' vol. xxxiv. (1888) p. 227, I find the following description of this rock by Dr. A. Schenck:—

"A characteristic rock which accompanies the strata of the Kaap Formation throughout South Africa, and here and there extends over a wide area, is a peculiar, blue-black, dolomitic limestone. It occurs both on the Huib and the Han-ami plateaux in Great Namaqualand, and also in Griqualand West, where it forms the so-called Kaap plateau, west of the Vaal, and extends from thence over a great part of Bechuanaland and a great part of the Western and Central Transvaal (Marico, Lichtenburg, Wonderfontein). Farther off it appears also in the Northern Transvaal, and on the Drakensberg (Pilgrims' Rest, Spitzkop, Krokodil River)."

In the geological map, pl. xiii., accompanying Dr. Schenck's paper, the position of the dolomite is marked; and it appears to be of great extent, especially in the Transvaal and Namaqualand.

In the Malmani district of the Transvaal the dolomite is intersected by numerous fissure-veins of quartz, bearing gold; but, owing to the immense difficulty experienced in draining the mines, the district has been abandoned by the gold-miners. It was found that underground channels of communication existed between the various streams and pools in the neighbourhood, and all attempts to free the mines from water proved abortive.

Lead, zinc, cinnabar, silver, gold, and other metals have been found in small quantities in the quartz-veins and pockets in the dolomite at Malmani, and at Lydenburg the same rock is being worked for gold.

In the Malmani district numerous large holes occur in the dolomite; some of these are of great extent; for instance, the 'Baviaan Gat,' near the village of Otto's Hoop, is about 100 yards in diameter at the surface, narrowing to about 60 feet in a depth of 120 feet, and at that depth is a pool of water 105 feet deep. These holes, 'Wonder Holes' they are called locally, have been caused by the disintegration of the rock by natural causes, and the eventual sinking of the surface-ground or roof, when too thin to support its own weight. In one cave near Otto's Hoop the roof has fallen in and the trees which grew on the surface are now found growing at the bottom of the cave.

Mr. Francis Galton, in his 'Tropical South Africa,' p. 200, describes water-holes similar to those at Malmani, as occurring at Otchikoto and Oriejo; and, judging from his description, it would appear that the dolomite occupies a large area in Ovampoland. Recent descriptions of the great caves in Mashunaland, and of the rocks in which they are situated, lead to the supposition that this rock extends to the neighbourhood of the Zambesi River.

It will therefore be seen that it occupies an important position in the geology of South Africa, and is worthy of more than a passing notice.

I have written this short communication in the hope that those who have the opportunity of studying the geology of South Africa will in future give particular attention to the 'dolomite,' if they happen to come across it during their travels.

In conclusion, I wish to record some observations that I have made during my travels in South Africa (extending over a period of thirty years), with regard to the surface-deposits of limestone-tufa, now occupying large areas in the drainage-basin of the Vaal and Orange rivers, and its relation to the dolomite. These beds of travertine are found only on the surface, dotted about the country, sometimes over small areas, but occasionally, as in the districts of Hope-Town, Boshoff, and Jacobsvaal, and in Griqualand West,[1] covering almost the entire surface of the country.

I have never found this tufaceous limestone except in such positions as to render it highly probable that the supply of lime required for its formation was derived from the dolomitic rocks of the Transvaal or of Griqualand West.

These surface-deposits of carbonate of lime occur at a lower level than the dolomite of the Transvaal, and are *never* found higher than that rock. Those portions of the Orange Free State and the Transvaal that lie higher than the dolomite are devoid of the limestone-tufa; and the soil of Natal, where the dolomite has not been discovered, is so devoid of calcareous matter that wheat will not yield a crop without the application of lime to the arable land.

The waters flowing from the dolomite of the Transvaal contain so great a quantity of lime that deposits occur wherever they become stagnant; and the mining town of Johannesburg rejected a scheme for supplying the town with water from Wonderfontein, on account of the quantity of lime held by that water in solution.

[For the Explanation of Plate XXIII., see p. 560.]

Discussion (on the preceding two Papers).

Mr. Rutley said that the paper on 'The Occurrence of Dolomite in South Africa' was especially interesting, as it appeared to afford a remarkably good instance of the replacement of limestones by silica, a point which he had already dealt with in a paper recently read before this Society, and in which one of the examples cited was a calcareous, gold-bearing quartzite from Nondweni in Zululand. Mr. Draper's suggestion that the extensive beds of calcareous tufa in South Africa were derived from the waste of the neighbouring dolomites, coupled with the occurrence of chert in those rocks and their graduation into quartzites, seemed to make up a very complete account of the changes which these calcareous beds had undergone. The occurrence of detached nuggets and groups of crystals of gold in a talus on a hillside might perhaps be due to the gold having originally occurred in limestone, which had been subse-

[1] [See G. W. Stow, Quart. Journ. Geol Soc. vol. xxx. (1874) pp. 615–617.—T. R. J.]

quently dissolved or partially disintegrated. In a microscopic section of the Nondweni quartzite the gold appeared to lie chiefly in the calcareous portions of the rock, although some of it was distributed through the quartzite itself.

Mr. Nicol Brown remarked that the dolomitic limestone at Pilgrims' Rest, which is apparently the 'elephant-rock' of Mr. Draper, underlies all the country in the neighbourhood. The limestone is eroded into valleys at Pilgrims' Creek and along the course of the river Blyde and elsewhere. On the top of the limestone lies a bed of manganiferous earth; over this come the beds of quartzite and chalcedolite represented by the specimens on the table, and on the top of the whole there are frequently masses of diorite, often decomposed.

Although the general dip of the strata is fairly represented by about 1 in 13 to the south-west, the local folds and contortions are numerous, and when he commenced to study the district it was almost impossible to follow the stratification. Numerous carefully registered specimens were sent home, and from these the succession of the rocks has been ascertained with some degree of certainty, with this practical result, that the rich gold-bearing zone is found to be immediately above the manganiferous earth.

Numerous sections of working-faces have since established the succession. It may be noted, however, that there are distinct indications of the gold-bearing beds sometimes running into the limestone, while sometimes the manganiferous earth overlies the gold-bearing beds. On the escarpments very little chalcedolite and quartzite are found detached from the hillside, but on the counter-escarpments very large masses of these rocks are spread over the hillside, and it is amongst these fragments on Brown's Hill that the nuggets exhibited at the Meeting were found.

The thickness of the limestone is not known; it has been eroded 500 or 600 feet in Pilgrims' Creek, but no bottom has been seen. The rock immediately underlying it is unknown.

Prof. T. Rupert Jones referred to Mr. Draper's view of the Ecca Beds thinning out, and the Molteno Beds thickening, northwards, in Natal and Zululand, and alluded to a specimen of the dolomite (exhibited by the previous speaker) from the Lydenburg district, with its associated auriferous quartz: this limestone had been tested and microscopically examined at the Royal College of Science, South Kensington.

37. *The* Igneous Rocks *of the* Neighbourhood *of* Builth. By Henry Woods, Esq., M.A., F.G.S. (Read June 20th, 1894.)

Contents.

I. Introduction and Bibliography.

In south-west Radnorshire a series of igneous rocks associated with beds of Ordovician age stretches from near Builth in the south to beyond Llandrindod in the north. This area is surrounded on all sides, except the north-west, by Silurian rocks, and has a length of about 7½ miles, and a width varying from 2 to 5 miles. The best account of the geology of this district is that given by Murchison in the 'Silurian System.' Short descriptions or notes have also appeared in memoirs and papers by De la Beche, Phillips, M'Coy, Ramsay, Symonds, Lapworth, and Rutley. The district is shown on sheets 56 S.W. and 56 S.E. of the Geological Survey, and was mapped by the late Sir Andrew Ramsay and by Mr. W. T. Aveline; the maps were issued in 1850, and were explained by two horizontal sections on Sheets 5 and 6, but no descriptive memoirs were published.

The following is the literature relating to this area of Ordovician and associated igneous rocks:—

Murchison, R. I.—'The Silurian System' (1839), pp. 314, 324–335, pl. xxxiii. figs. 5–7.

Murchison, R. I.—'Siluria,' 5th ed. (1872) pp. 59, 81.

De la Beche, H. T.—'On the Formation of the Rocks of South Wales and South-western England,' Mem. Geol. Surv. vol. i. (1846) p. 22.

Phillips, John.—'The Malvern Hills,' etc., Mem. Geol. Surv. vol. ii. pt. i. (1848) pp. 227–315, 327.

M'Coy, F.—'British Palæozoic Fossils' (1852), pp. 354, 369, 373–74. [Lists of fossils.]

Ramsay, A. C., H. W. Bristow, H. Bauerman, and A. Geikie.—'Catalogue of the Rock Specimens in the Museum of Practical Geology,' 2nd ed. (1860) pp. 112, 197, 211, 212, 248.

Symonds, W. S.—'Records of the Rocks,' 1872, p. 93.

[Newton, E. T.]—'A Catalogue of the Cambrian and Silurian Fossils in the Museum of Practical Geology,' 1878, pp. 23–29. [Lists of fossils.]

Lapworth, C.—Ann. & Mag. Nat. Hist. ser. 5, vol. iv. (1879) p. 339.

Rutley, F.—'The Felsitic Lavas of England and Wales,' Mem. Geol. Surv. 1885, p. 20.

In the present paper I propose to deal with the igneous rocks of the southern half of this district—that lying between the town of

Builth and a line drawn from Cwm-amliw, eastward to Garth, and then round the Castle Bank; and shown in the accompanying map (p. 568). The rocks met with are diabase-porphyrite, andesite, andesitic ash, rhyolite, rhyolitic ash, and diabase. These give rise to characteristic hummocky ground, with here and there a few prominent peaks, forming a marked contrast to the regular features of the neighbouring Ludlow escarpment. A good example of the scenery of the district is given in the 'Silurian System' (plate facing page 330), from a drawing made by Lady Murchison.

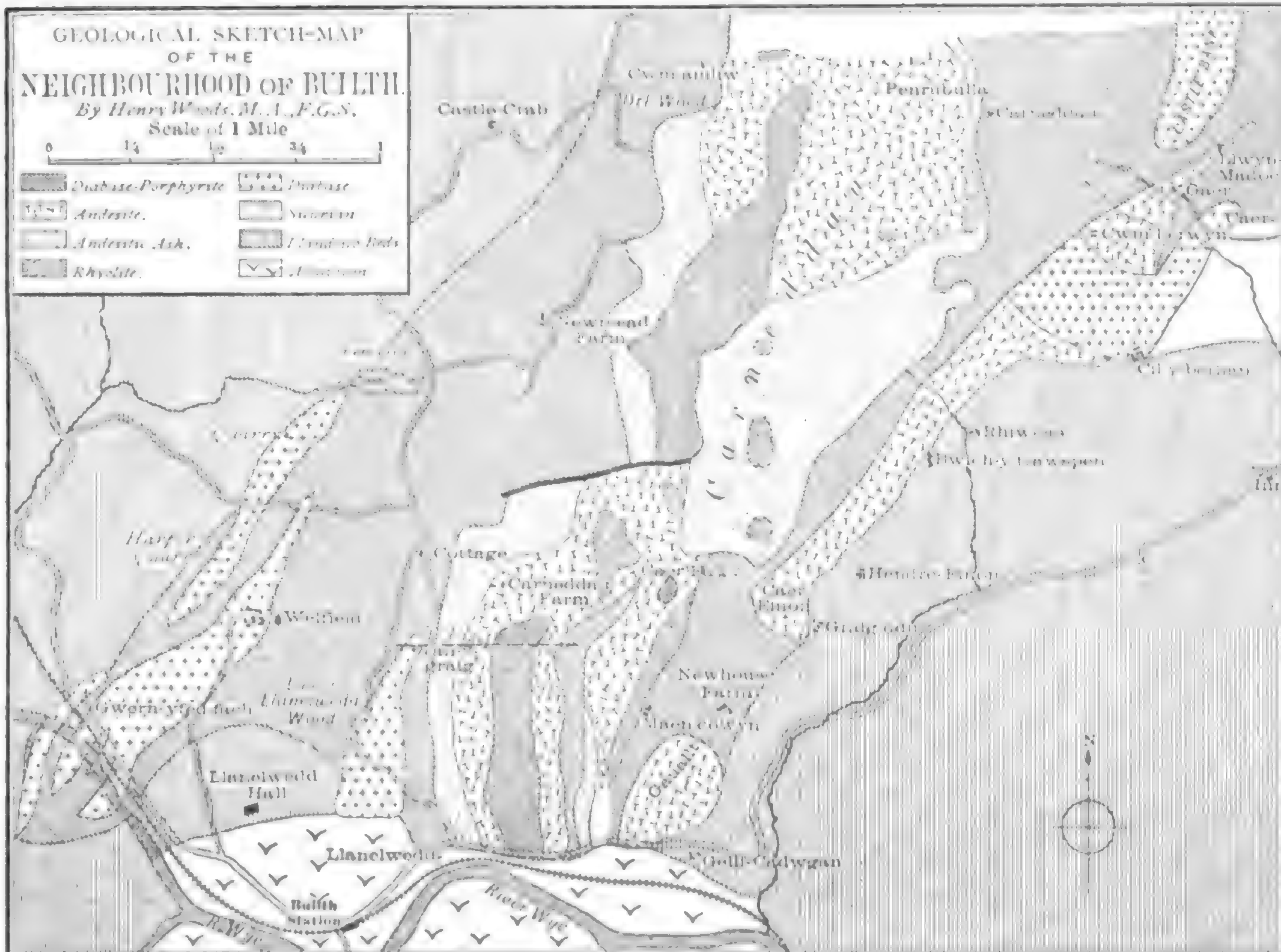
II. The Diabase-Porphyrite.

This is the most conspicuous rock in the district; it consists of a dark-coloured, fine-grained base, much decomposed, containing numerous light felspars of large size, and often having a greenish tinge; in some cases these porphyritic felspars become much smaller. The diabase-porphyrite occurs in four masses, extending in a north-and-south direction, and is intrusive in the andesites and andesitic ashes, possibly in a laccolitic form. The first of these, commencing in the south, forms the central part of the tract known as the Llanelwedd Rocks, extending from the Rock House nearly to Carneddau Farm, and is surrounded, except on the south, by andesite. The second, which is more irregular in form, occurs to the north-east of Carneddau Farm, and is intruded into the andesite. The third is the smallest mass, and forms the eastern part of Caer Fawr, which reaches a height of 1267 feet. The fourth is the largest, and extends along the western part of the Carneddau Hills for a distance of a little over a mile; it is intruded into the andesite and andesitic ash.

Under the microscope the earlier plagioclase-felspars in this rock are seen to be considerably decomposed; the base consists of small plagioclase-felspars and augite, with some, and frequently much pale green chlorite. In a few cases, as for instance in a specimen from near the Rock House, the augite has entirely disappeared, the base being composed of felspar and chlorite. Ilmenite and leucoxene are often present. Frequently there are large irregular vesicles filled with chlorite or calcite. In some sections the later felspars are markedly lath-shaped, but they do not exhibit any flow-arrangement.

The silica percentage of the diabase-porphyrite is 48·36, and its specific gravity 2·78.

On the Geological Survey map (56 S.W.) a continuous mass of 'greenstone' is shown, extending from Llanelwedd Church northwards, to near Cwm-amliw; this was probably intended to represent the diabase-porphyrite, since on the horizontal section (Sheet 5, No. 1) it is spoken of as 'greenstone porphyry,' but it includes, in addition to the diabase-porphyrite, a considerable area of andesite and andesitic ash.


GEOLOGICAL SKETCH-MAP
OF THE
NEIGHBOURHOOD OF BUILTH.
By Henry Woods, M.A., F.G.S.
Scale of 1 Mile
0
1/4
1/2
3/4
1
Diabase-Porphyrite
Diabase
Andesite.
Andesitic Ash.
Rhyolite.
Castle Crab
Penrhulla
Cottage
Carneddau Farm
Newhouse Farm
Gelli-Cadwgan
Llanelwedd
Llanelwedd Hall
Builth Station
R. Wye
River Wye
Gwern-y-fed-fach
Hendre Farm
Llanelwedd Wood
Carneddau

III. The Andesites.

The andesites are widely distributed in this district; there are four areas, which will be described in the following order: (1) surrounding the three southern masses of diabase-porphyrite; (2) around the northern part of the largest mass of diabase-porphyrite; (3) north of Gelli-Cadwgan; and (4) extending from Caer Einon to Llwyn-Madoc, except where broken into by the diabase near Cwm-berwyn.

(1) The andesite between Llanelwedd and Carneddau Farm, on the west of the Llanelwedd diabase-porphyrite, forms a well-marked type: it is, when fresh, a dark-green compact rock, and on a weathered surface shows a thin white crust. Good specimens may be collected at between $\frac{1}{3}$ and $\frac{1}{2}$ mile north of the Rock House: in these, crystals of felspar and augite may be seen with the unaided eye. Under the microscope, sections show a groundmass formed mainly of minute felspars, exhibiting in places flow-structure: in this porphyritic plagioclase-felspars occur; they are rather decomposed, and sometimes contain irregular inclusions of the groundmass. Augite is also rather abundant; it is colourless and quite fresh. A pale green, rhombic pyroxene, showing distinct pleochroism and a slightly fibrous structure, is fairly common; it is probably an altered enstatite. Ilmenite associated with leucoxene is present, and also small crystals of magnetite. The silica-percentage of this rock is 50·8 and its specific gravity 2·74.

The andesite on the eastern side of the Llanelwedd diabase-porphyrite differs considerably from that on the west just described: it is much more decomposed and of a dull greenish colour. Under the microscope it is seen to be formed of porphyritic plagioclase-felspars in a base of minute felspars; there is very little augite, and enstatite is absent; chlorite is abundant, and there is a little calcite. The rock has a specific gravity of 2·702.

The andesite, extending north of the Llanelwedd diabase-porphyrite up to the southern border of the largest mass of the same rock, is green or greyish in colour, sometimes light, sometimes dark; the felspars in many cases are seen as glistening lath-shaped crystals, in others they are milky-white and rather irregular. Sections show that the groundmass of the rock is made up of a brownish isotropic material containing numerous small felspars generally having a flow-arrangement; sometimes there are also irregular granules of a semi-opaque substance. The phenocrysts consist of plagioclase-felspar, and, in some slides, of an altered rhombic pyroxene: augite is rare and often absent.

This same mass of andesite is continued southwards by Caer Fawr down to the Big Wood. A section from the south-western part of Caer Fawr is similar to those just described, but is more decomposed and contains much chlorite: another from the southern part of the Big Wood shows a particularly good flow-structure in the later generation of felspars, and also contains a large quantity of calcite.

(2) The second area of andesite surrounds the northern part of the largest mass of diabase-porphyrite. Specimens of this, from a spot just south of Cwm-amliw and east of Orl Wood, are dark grey or almost black in colour, and one can distinguish with the unaided eye felspars, calcite, and a dark green mineral. Under the microscope the earlier plagioclase-felspars are seen to be very much decomposed; usually they have a length of about 3 mm. The later felspars are very much smaller; the groundmass contains, in addition, a semi-opaque material, and a large quantity of magnetite, the latter generally having the form of skeleton-crystals. Augite occurs very sparingly, but not as a constituent of the groundmass. Numerous large and often irregularly-shaped vesicles are present, having a diameter varying from ·7 to 2 mm. These in some cases contain calcite in the centre, around which is a narrow band of a pale green mineral, probably delessite, and external to this is a zone of quartz. In other cases the vesicles do not contain calcite, but are occupied by delessite with a border of quartz. At other times, almost the whole of the vesicle is filled with calcite, with here and there a little quartz or delessite at the margin. Quartz and calcite also occur in the groundmass as secondary minerals. The specific gravity of the rock is 2·77.

The rocks on the east of the diabase-porphyrite, which form the main part of this area of andesite, are occasionally dark in colour, but mostly light grey with sometimes a bluish or greenish tinge, and generally showing crystals of felspar. A section from the ridge immediately north-west of Penrubulla shows a groundmass composed mainly of small felspars, containing porphyritic crystals of plagioclase, which are considerably decomposed; there is also some secondary quartz. Similar features are seen in sections taken from the ridge north-west of the last 'a' in Carneddau (and north of B.M. 1322),[1] and from the ridge south-west of Carneddau House and immediately north of the first 'L' in Llansantffraid; the first of these, however, differs in containing a large quantity of secondary quartz. Specimens from the ridge $\frac{1}{8}$ mile west of Carneddau House were also sliced. In these the porphyritic felspars are very large, and so much decomposed that the twinning is only indistinctly seen and is sometimes quite absent; not unfrequently they have been entirely replaced by secondary quartz. The groundmass of the rock consists of a semi-opaque substance, and small felspars more or less felted together; it also contains some secondary quartz and a little calcite. A few small vesicles containing quartz or chlorite are present.

(3) The field-relations of the andesite north of Gelli-Cadwgan are not very well seen, but apparently it is intrusive in the Llandeilo Beds. The rock is quarried near its south-western extremity by the roadside, and is used as road-metal; it is compact, of a light grey colour, with here and there dark streaks, and is

[1] These are references to the 6-inch Ordnance Maps.

well jointed in a roughly cuboidal manner. A specimen from this quarry was found to contain 57·73 per cent. of silica, and to have a specific gravity of 2·639. Under the microscope it is seen to be formed of a base of small, rather irregular felspars, with a few porphyritic crystals of plagioclase; there is also some secondary quartz. Other sections taken from specimens collected at different spots between the quarry and Gauallt Wood are similar to the last, but the porphyritic felspars are larger, and the smaller felspars of the groundmass have more regular outlines and show a well-marked flow-arrangement.

(4) The last area of andesite extends from Caer Einon in a north-easterly direction to Llwyn-Madoc, a distance of a little more than 2 miles; but this is broken into by a mass of diabase between Cwm-berwyn and Cil-y-berllan.

Sections from various parts of Caer Einon show numerous rather large porphyritic plagioclases, and a base composed mainly of small felspars, generally with a good flow-structure, and containing vesicles of irregular shape filled with a pale green, fibrous, chloritic mineral. The same features were seen in a section from near Bwlch-y-trawspen.

Another slice was cut from a specimen collected at a spot $\frac{1}{8}$ mile north of Rhiw-lâs and 70 yards east of the stream which runs to Rhiw-lâs; this shows distinct evidence of crushing, the felspars have a parallel arrangement, and numerous bands of quartz are present. Limonite also occurs, sometimes showing eight-sided sections, apparently as a pseudomorph after augite.

Between Cwm-berwyn and Llwyn-Madoc I was only able to find exposures near Gaer; the rock is here rather dark in colour, and contains felspars, chlorite, and a small quantity of augite.

IV. The Andesitic Ashes.

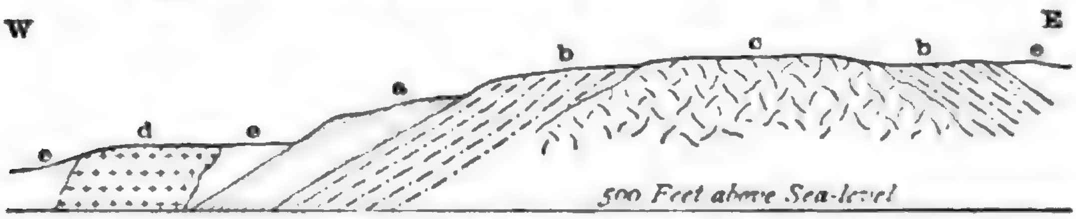
A belt of andesitic ash extends from Llanelwedd to Orl Wood, forming the western boundary of the volcanic series, and being overlain by Llandeilo Shales; just north of Wern-tô its outcrop is shifted by a dip-fault. When fresh the rock is of a light bluish-grey colour, and has a gritty feel; it is well exposed in numerous quarries between Llanelwedd and Wye Cottage, and is largely used in the neighbourhood for building. Specimens from these quarries were found to have a specific gravity of 2·66 and a silica-percentage of 51·10. Under the microscope, sections taken from Tan-y-graig and other quarries to the south show numerous irregular fragments of plagioclase-felspar, embedded in a fine-grained base containing chlorite and calcite; some fragments of andesite are also present.

The lower part of the ash in some of the quarries, particularly at Tan-y-graig, contains numerous well-rounded pebbles of andesite; they are usually 5 or 6 inches in diameter, but one example I saw had a length of 2 feet and a breadth of 1½. Under the microscope the pebbles are seen to resemble more closely the

andesite on the east of the Llanelwedd diabase-porphyrite than that on the west. The specific gravity of one of the pebbles was found to be 2·58, and the silica-percentage 51·6.

Fossils are not very common in the ash, but I have found several specimens of *Orthis calligramma*, Dalm. M'Coy[1] also records the following, which are preserved in the Woodwardian Museum:—*Crania divaricata* (M'Coy), *Leptæna sericea*, Sow., and *Serpulites dispar*, Salt.[2] In the third quarry south of Tan-y-graig I also found specimens of what appear to be polyzoa. Dr. Gregory kindly examined these, and he says that they seem to be allied to the genus *Drymotrypa*. These species are not sufficient to fix the horizon of the ash, but as it is overlain by Llandeilo Shales containing *Ogygia buchi*, etc., it is probably of Lower Llandeilo age.

Fig. 1.—*Section immediately south of Tan-y-graig.*



[Scale: 1 inch = 880 feet.]

a = Andesitic ash.
b = Andesite.
c = Diabase-porphyrite.
d = Diabase.
e = Llandeilo Shales.

On the Geological Survey map the ash just described is shown as greenstone, but this appears to have been a slip in colouring, since its nature is correctly indicated on the Horizontal Section (Sheet 5, No. 1), where it is spoken of as 'Trappean Conglomerate' in the first edition, and 'Felspathic Tuff and Conglomerate' in the second.

In the lowest part of the quarry at Tan-y-graig, underneath the andesitic ash, is seen a greyish rock with numerous white felspars, resembling closely, in hand-specimens, the diabase-porphyrite already described; under the microscope, however, it is seen to be quite different from that rock. It is composed of a fine-grained base containing plagioclase-felspars of various sizes and usually of irregular outline; some calcite and chlorite are also present. Although my sections are not absolutely conclusive, I think there can be little doubt that the rock is an ash: its silica-percentage is 61·44.

[1] 'British Palæozoic Fossils' (1852), p. 373.

[2] The Rev. T. C. Davies, formerly of Builth, informs me that many years ago he found in the ash at Tan-y-graig a specimen of *Asaphus tyrannus*, and believes that he gave it to Dr. Grindrod. No reliance, however, can be placed on the determination of the species. On Horizontal Section No. 1 of Sheet 5 (Geol. Survey) there is written under the ash at Tan-y-graig '*Asaphus laticostatus*,' but Mr. E. T. Newton, F.R.S., informs me that the specimen is not in the Museum of Practical Geology, and he thinks it must have come from the Llandeilo Shales, not from the ash, since Salter, in his Monograph on the Trilobites (p. 158), says that the only specimen known is a tail from the Llandeilo Flags of Maen Goran, near Builth.

Another area of andesitic ash stretches from just north of Caer Einon and Caer Fawr to near Penrubulla. In hand-specimens this is sometimes dark in colour, but often light grey or bluish, and occasionally shows distinct white felspars; in some cases, as for instance near the northern diabase-porphyrite, it is mixed with a certain amount of sedimentary material, and is well stratified.

Sections taken from the three following spots are almost identical:—(1) 140 yards north-east of Penrubulla; (2) the 'Camp' west of Cwm-berwyn; (3) 'Old Quarry' east of Newmead Farm; these show numerous fragments of plagioclase-felspar of various sizes and usually irregular in outline; the groundmass contains a large quantity of a yellowish-green chloritic mineral and a fair amount of secondary quartz, the latter sometimes replacing the felspars. In some parts of the slides there are groups of very small (usually oval) vesicles with dark borders, and containing the yellowish-green chloritic mineral, or, occasionally, quartz. A few small fragments of andesite are also present. Another slide from just north-west of Caer Einon is similar, but the rock is more decomposed and contains a large quantity of calcite. A section from a little more than $\frac{1}{4}$ mile north of the summit of Caer Einon,[1] and another from $\frac{1}{2}$ mile north of Bwlch-y-trawspen and $\frac{1}{4}$ mile south-south-west of the 'Camp,' differ from those just described in containing very little chlorite, and in the felspars being larger and more numerous.

There is a small area of ash just south of Big Wood; in its southern part this is dark in colour and rather coarse, but northwards it becomes lighter and finer-grained. A specimen collected at 70 yards south of Big Wood is very similar to those described above from Penrubulla, etc., except that it contains very few vesicles. A section from the southern part of Big Wood (almost due west of Maen-cowyn) differs in having the felspars much smaller; in another from $\frac{1}{4}$ mile south of Big Wood, small elongated vesicles are very numerous in some parts of the slide.

V. The Rhyolites.

In this district the rhyolitic rocks cover only a small area; they occur as isolated patches between Maen-cowyn and Penrubulla. In hand-specimens they are usually compact and of a dark grey colour, or, when weathered, yellow or white, and often contain porphyritic felspars. Some of these rhyolites may possibly be intrusive.

A section from a specimen collected $\frac{1}{5}$ mile south-south-west of

[1] At a spot $\frac{1}{3}$ mile north-north-west of the summit of Caer Einon, I found a large block of black chert; it was not *in situ*, but I think it could not have travelled more than a very short distance. Under the microscope this chert is remarkable for the large size of the sponge-spicules which it contains, some of them being 5 mm. in diameter. Dr. Hinde kindly examined the slides, and he informs me that the spicules belong to the anchoring-ropes of hexactinellid sponges, and that there is a piece of Llandeilo Shale from near Builth in the Museum of Practical Geology containing similar spicules.

Maen-cowyn shows under the microscope a cryptocrystalline groundmass, with here and there small microcrystalline patches. The porphyritic felspars are twinned on the albite type, sometimes combined with the Carlsbad or with the pericline type. The other slides differ from this chiefly in the relative proportions of the cryptocrystalline and microcrystalline material in the groundmass. In some sections there are bands of quartz. Spherulitic structure has not been met with in any case.

The rhyolite has been found to be nodular only at one spot, namely, $\frac{2}{3}$ mile east of Newmead Farm, and a little more than $\frac{2}{3}$ mile north of Caer Einon. The nodules stand out on a weathered surface of the rock, and can be easily detached: as a rule they are very irregular in form, and of small size, sometimes being 2 inches in diameter, but often less. They are solid throughout, and in section are seen to be formed of microcrystalline quartz and felspar, and to show no trace of either a radial or concentric arrangement; in fact the structure does not differ from that of the groundmass of some of the ordinary rhyolites. The silica-percentage of one nodule was found to be 72·1.

Rhyolitic ashes have been met with at the following spots:—Immediately north of Maen-cowyn; north of Caer Fawr; at $\frac{1}{3}$ mile, and also at a little more than $\frac{1}{2}$ mile west of Cwm-berwyn.

VI. The Diabases.

The diabases are of later date than the rocks previously described, and may therefore conveniently be considered last. They are all intrusive in the Llandeilo Shales, and are found on the east and west of the main volcanic series. The minerals which occur in the diabases are plagioclase-felspar, augite, magnetite, ilmenite, leucoxene, apatite, chlorite, and secondary quartz and calcite. The plagioclase is generally much decomposed, and the augite in most cases ophitic.

On the west, between the town of Builth and Pen-cerig, there are four sills of diabase. The northernmost stretches from Pen-cerig in a south-westerly direction for about $\frac{3}{4}$ mile. It is well exposed in the quarries at the north-western edge of Pen-cerig Wood, and at Pen-cerig Lake; also in the road-cutting at the back of Pen-cerig House (fig. 2, p. 575). At the two last-named localities the junction with the Llandeilo Shales, containing the following fossils, is seen: *Ogygia buchi* (Brongn.), *Ampyx nudus* (Murch.), *Trinucleus fimbriatus*, Murch., *Barrandia cordai*, M'Coy, *Siphonotreta micula*, M'Coy, etc.

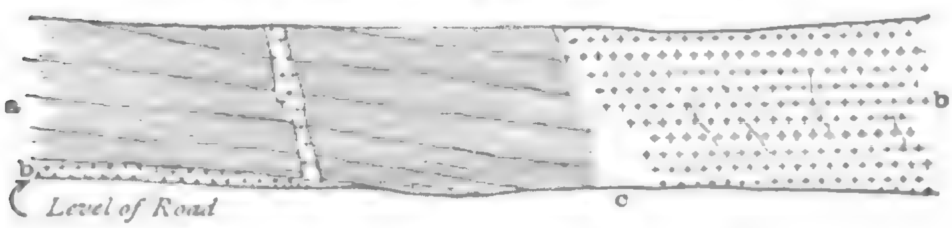
The rock in the quarry at the north-west of Pen-cerig Wood is a medium-grained and rather decomposed diabase, having a specific gravity of 2·75. The augite is colourless, and occurs in ophitic plates. Leucoxene forms large grains and is often associated with ilmenite.

The rock at Pen-cerig Lake is finer-grained than the preceding, and in hand-specimens differs considerably in appearance. The microscope shows that the augite is usually scarce, and in one slide

entirely absent, its place being taken by chlorite. There is also a large amount of secondary quartz and calcite.

In the road-cutting at the back of Pen-cerig House the rock resembles, in hand-specimens, that of Pen-cerig Wood. At the junction of the diabase with the Llandeilo Shale, the latter is, for a space of 3 or 4 inches, converted into a hard, grey, porcellanous rock; beyond this it does not differ from an ordinary black shale,

Fig. 2.—*Section seen in the road-cutting at the back of Pen-cerig House.*



[Length of section = about 18 yards.]

a = Llandeilo Shales. b = Diabase.
c = Junction of shale and diabase, obscured at this spot.

except in being somewhat more indurated. A section of a junction-specimen shows that the line of division between the two rocks is well defined. The igneous rock has become very fine-grained, consisting of minute felspars and chlorite; some secondary quartz is present, and a large amount of calcite. The shale next the diabase shows a fine-grained groundmass in which occur what appear to have been cavities, some of which are now filled with quartz, others with a pale-green chloritic mineral, often possessing a radiating fibrous structure. There are also large irregular patches of calcite.

In Harper's Quarry,[1] ½ mile south-west of Pen-cerig House, the diabase is seen on the southern side above the Llandeilo Beds; the latter are altered into a hard, compact, and well-jointed rock, having a black or light grey colour. The igneous rock is rather fine-grained, and consists of the usual minerals, but the augite is now represented by pale green chlorite; and there is a large amount of a semi-opaque material and calcite.

The western sill, the smallest of the four, extends from just north of Gwern-y-fed-fâch across the Wye to Park Wells. It is exposed near Gwern-y-fed-fâch, in the bed of the Wye, in a quarry at Park Wells, and in a road-cutting north of Park Wells, where the junction with the Llandeilo Beds is seen. It is rather a fine-grained greyish rock: a section of a specimen from north-west of Gwern-y-fed-fâch shows the plagioclase to be rather less abundant than usual, but very much decomposed; the augite is clear and colourless, and occurs in ophitic plates extending over large areas and enclosing numerous felspars; magnetite occurs in irregular

[1] The fossils found in the Llandeilo Beds here are remarkably well preserved, and include, amongst others, *Ogygia buchi* (Brongn.), *Trinucleus fimbriatus*, Murch., *Ampyx nudus* (Murch.), and *Siphonotreta micula*, M'Coy.

grains; there is a large amount of chlorite and some leucoxene. Minute crystals of brown mica and magnetite occur clustered together in little groups. A section taken from the southern end of the sill, near Park Wells, is similar to the one just described, but the place of the augite is taken by chlorite.

The largest sill is the one to the east of the two preceding, forming the high ground on which Welfield is situated. It is not exposed in any quarries, but may be seen in the bed of the Wye and at Pen-maenau Rocks. A section from the Wye, near Pen-ddol Rocks, shows the ordinary minerals.

The sill to the north-west of Llanelwedd Church, on which Upper Llanelwedd Wood is situated, is more irregular in form than the others; it is not well exposed, and in hand-specimens resembles the rock at Pen-cerig Wood. In a section from near 'w' in Upper Llanelwedd the augite is rather scarce; ilmenite, leucoxene, and chlorite are plentiful.

We come now to the diabases on the east of the main volcanic series. The most important is that which forms the ridge known as the Castle Bank.[1] This stretches from Llwyn-Madoc northwards almost to the Cannant Brook. Specimens collected from various parts of the Bank exhibit to the naked eye a fairly uniform appearance, the differences being due mainly to the amount of weathering; the rock is always rather fine-grained. In a specimen from 70 yards north-north-east of the 'Castle' the felspar is abundant and very much decomposed. The augite is in rather small quantity; it is almost colourless and not ophitic. There is a large amount of a green chloritic mineral, which in some cases is derived from the augite; in others it shows a fibrous structure, and possibly represents a rhombic pyroxene. Secondary quartz is abundant; magnetite, ilmenite, and leucoxene also occur. The silica-percentage of the rock is 54·54, and its specific gravity 2·73. Another section taken from the south-eastern part of the Bank, just north of the 'Carn,' shows similar characters; but the augite is sometimes idiomorphic.

Another mass of diabase occurs a little to the south of Llwyn-Madoc; it extends from the Caer to Cil-y-berllan. A specimen from near the road south of the Caer is similar in appearance to the Castle Bank rock. But under the microscope it differs from that in the augite being more abundant and generally ophitic; there is a little secondary quartz. Another section, taken from about 150 yards north-north-east of Cil-y-berllan, was very similar to the last. On the west side, south of Cwm-berwyn, the rock has rather the structure of a dolerite than that of a diabase: it is much finer-grained, darker in colour, and comparatively fresh; the augites are mostly very small, and never ophitic, and there are two generations of felspar, although the earlier is not well marked; the specific gravity of this rock is 2·81.

[1] The northern part of this ridge is not shown in the map which accompanies this paper.

VII. Conclusions.

There remain now to be considered the age and order of eruption of these igneous rocks. As already pointed out, the fossils at present found in the andesitic ash are not sufficient to fix its age, but since it is overlain by Llandeilo Shales containing *Ogygia buchi*, etc., it may be regarded as probably of Lower Llandeilo age; so also may the underlying andesites. The diabase-porphyrite and the rhyolites are somewhat later than these, but at present there is no evidence to show whether the rhyolites are earlier or later than the diabase-porphyrite; from theoretical considerations one would expect them to be earlier.

The diabases are of later date than the other igneous rocks, since in all cases they are intruded into the Llandeilo Shales; but nowhere do they pierce the Silurian beds (Llandovery and Wenlock), showing that they are of post-Llandeilo and pre-Silurian age. This is well supported by the section exposed in the quarry next Pen-cerig Lake, where the diabase is seen in contact with both the Llandeilo Shales and the Llandovery Beds: the former are metamorphosed, the latter quite unaltered.

The order of eruption, then, in this district was probably as follows:—(1) Andesites; (2) Andesitic Ash; (3) Rhyolites; (4) Diabase-Porphyrite; (5) Diabase. The first four are of earlier date than the Upper Llandeilo Shales, the last one later.

I must here express my thanks to my friends Mr. J. E. Purvis, B.A., and Mr. H. Brownsword, B.A., for their kindness in determining the silica-percentages given in this paper.

Discussion.

Dr. Hicks said that he had examined the area referred to by the Author, and he had come to the conclusion that the contemporaneous volcanic rocks were quite at the base of the Llandeilo Series, and mainly associated with the Llanvirn Beds—as in Pembrokeshire and North Wales.

Mr. W. W. Watts wished to ask whether there was any strong reason for placing the andesitic and rhyolitic ashes in the Llandeilo Series rather than linking them with the Arenigs. He pointed out that, while the general characters of the rocks agreed closely with those of Shropshire, the diabases in the latter county were indubitably of post-Silurian age.

38. *On the* RELATIONS *of some of the* OLDER FRAGMENTAL ROCKS *in* NORTH-WESTERN CAERNARVONSHIRE.

By Prof. T. G. BONNEY, D.Sc., LL.D., F.R.S., F.G.S.,[1] and Miss CATHERINE A. RAISIN, B.Sc. (Read June 20th, 1894.)

CONTENTS.

I. GENERAL CONSIDERATIONS.

IN a recent paper published in the Quarterly Journal of the Geological Society,[2] a new and revolutionary hypothesis is put forward as to the age and position of certain well-known conglomerates and associated beds in North-western Caernarvonshire. The new explanation presents at once some difficulties, but these have been increased in number and gravity by a fresh study of the district. We selected those portions of it examined by Mr. Blake, in which the more critical sections occur, and tested with the microscope the questions raised by work in the field. The one or the other author was already in possession of a fair number of slides from the district in dispute, and nearly fifty additional specimens have been expressly prepared for the present paper.

According to the new hypothesis, the strata previously mapped and described from near Llyn Padarn and from neighbouring districts can be distinguished into two groups separated by a strongly marked unconformity. While the one part is held by Mr. Blake to be of early Cambrian age, the other is 'post-Llanberis.' A question at once suggests itself, namely, to what epoch (from the Menevian onwards) do these so-called 'post-Llanberis' sediments belong, and where in adjacent districts may we find beds that can be correlated with them? Of this problem Mr. Blake has not succeeded in offering a solution, but he evidently perceives that it is one which claims consideration.

The new hypothesis, however, would involve two consequences of far-reaching import. The unconformity is described as being marked by nearly horizontal beds overlying earlier strata approximately vertical in position. Such an unconformity would be the record of

[1] The larger share of the work in this paper has been done by Miss Raisin. She has visited all the sections, often more than once. There are some which I have not examined, and others which I have not seen since the date of my former paper. It is only just that I should make this clear.—T. G. B.

[2] 'On the Felsites and Conglomerates between Bethesda and Llanllyfni, North Wales,' Quart. Journ. Geol. Soc. vol. xlix. (1893) pp. 441–465.

tremendous disturbances. The uplifting and denudation of the earlier strata, previous to a renewal of deposition, are changes which we should expect to find associated with a period of mountain-making. This can be no local phenomenon[1]: its record must extend over a wide area. Yet nowhere in the surrounding districts do we find evidence of such a break throughout the whole of the Cambrian and Ordovician periods—unless we concede that Mr. Blake has established the existence of one, farther north, immediately before the beginning of the Arenig epoch. Of even this hypothesis, however, he declines to avail himself here,[2] so that a second great break must be introduced. Yet, so far as we know, there is no certain evidence of the existence of either. Only when we arrive at the commencement of the Upper Llandovery age have geologists agreed in recognizing one comparable with this in importance. This difficulty is dismissed in a few inconclusive sentences. Yet it is one which no detailed observation, no withdrawal of any small part of the evidence can possibly meet. It is general, and must be dealt with before the hypothesis can have any solid foundation.

The other difficulty, which is not even considered, is partly connected with the preceding one. It is the necessity of twice uncovering the felsite[3] in order to obtain from it a great amount of material to help so largely in forming the two series of strata, the one before, the other after, the tremendous break we have mentioned.[4] So complete was the exposure of the felsite in what he takes for the second period that Mr. Blake describes this 'post-Llanberis' conglomerate as shading into the 'reconstructed' felsite.[5] But the denudation cut even deeper, since the so-called later conglomerate includes granitoid and quartzite-pebbles, which must have been obtained from early pre-Cambrian rocks. Yet, curiously enough, the 'Llanberis' strata, though they have been so completely planed down, have not contributed any large amount of fragments. Only exceptionally do we find these or slaty pebbles of any kind, as, for example, at Moel Tryfaen. The detailed evidence, then, ought to be

[1] Mr. Blake says it has to be decided whether 'this unconformity is any more than a local one' (*op. cit.* p. 465). But surely, were it local, this would require such exceptional and extraordinary conditions as to be practically impossible.

[2] *Ibid.* p. 465. The unconformity which has been claimed in some previous papers, as separating the Cambrian from the pre-Cambrian, would not of course help Mr. Blake; and this presents no serious physical difficulties.

[3] We refer to the well-known mass which is shown in the Geological Survey map as near Llyn Padarn, and as extending for a considerable distance from Bethesda to the S.W.

[4] Although the so-called earlier 'Llanberis Beds' generally are finer-grained, they can be clearly proved to be at places mainly composed of material derived from the quartz-felsite. As examples we may mention beds in some of the 'banded slates' synclinal east of Llyn Padarn, and the 'more felsitic material . . . . almost . . . . pure felsitic ash,' described by Mr. Blake south of the second conglomerate (*op. cit.* p. 445).

[5] *Ibid.* p. 447. Thus, apart from other objections, Mr. Blake's hypothesis of several successive felsites (*e. g.* Moel Goronwy) and their denudation will not lessen the difficulty referred to above, since here (and at other places) the 'post-Cambrian' conglomerate is supposed to be deposited on one of the earlier felsites.

of the strongest and clearest nature, if it is to establish the supposed unconformity. This evidence, in all places but one, is indirect; we will consider that instance first, and then pass on to the other cases.

II. Evidence from Moel Tryfaen.

This locality is the one which seems at first sight most to support Mr. Blake's hypothesis. As we were unable to spare the time for any thorough re-investigation of the adit,[1] we have considered how far the surface-exposures, taken in conjunction with Mr. Blake's description of the tunnel,[2] necessitate the acceptance of his hypothesis. The general succession crossed on the western slope above and north of the Bryngwyn incline (that described as 'the southern slopes') is claimed as representing the tunnel-section, but it is not very clear how the author accounts for the absence from the tunnel of the conglomerate of the tramway-cutting.[3] This is at a lower level and strikes towards the adit, which, it is admitted, commences in felsite.

The main difficulty, however, is the apparent absence of the summit-conglomerate from the tunnel. Certainly nothing in the detailed section given by Mr. Blake can fully represent the extensive outcrop on the top of the hill. Assuming the accuracy of his observations of the tunnel, there seems on our theory no other explanation possible than that this conglomerate is faulted out; and the broad outcrop at the summit might be due partly to such disturbance. This seems suggested by the changed dip found in the associated green grits.[4]

The chief arguments drawn by Mr. Blake from the surface exposures are, that the dip is nearly horizontal, and that the northern slopes are covered by conglomerate and grit. Special reference is made to two lines of crags in this direction. It is said that the upper "most distinctly show a low dip of not more than 5° to the east" (*op. cit.* p. 462). We took the dip on several blocks and surfaces, of which four at least were clearly shown varying from 15° to 25° generally to S. of E. or S.E.[5]; while in the grit of the summit-

[1] Each of us on separate occasions has been through it, but not with good lights.

[2] That difference of opinion is possible would appear from the fact that a specimen which one of us collected at a hundred paces from the mouth or northern end of the adit, that is, somewhere in '29, light crystalline felsite,' is an unquestionable felsitic grit.

[3] Prof. Bonney in 1878 collected a specimen from the spoil-bank at the N.W. mouth of the adit which closely resembles this conglomerate, and noted 'Cambrian conglomerate' as one of the four varieties of rock lying about. In 1880 he passed through the adit (but only with a bull's-eye lantern) and found 'Cambrian conglomerate' following after the felsite with (?) some felsitic grit. This is probably identical with the rock mentioned by Mr. Blake in a note (*op. cit.* p. 460).

[4] These do occur, although Mr. Blake says (*op. cit.* p. 462):—'nor can we find any green grit on the summit.'

[5] These, in some cases, are the dips shown on exposed surfaces, and so may be less than the true angle.

crags the dip is distinctly as much as 40° to a westerly or south-westerly point (approximately W.S.W.).

It is then said that "the lower crags are of conglomerate like that of the summit." The rock clearly is a conglomerate, one of those largely made up of material from the quartz-felsite, with pebbles also of quartzite and occasionally of granitoid rock, while the large slate-fragments of the mass at the top of the hill are wanting. Thus it seems to us that lithologically this conglomerate does not resemble that of the summit; it more probably represents a band at a different level, like that of the tramway-cutting. The argument implied in the words "all is covered by conglomerate and grit" is less strong than it seems, because no small part consists of unbroken sward. So far as any inference is justifiable from the latter fact, it would be that there probably is a softer rock, such as slate, in this part of the hill.

Thus it does not appear that we can prove the conglomerates on the hill to form a single great mass, or that this is approximately horizontal as implied by Mr. Blake[1]: hence we are still not satisfied "that the conglomerate lies unconformably on, and is independent of, the underlying members of the Cambrian Series" (*op. cit.* p. 463).

III. West of Llyn Padarn.

In the district west of Llyn Padarn we will discuss first that part of the railway-section where the evidence can be best brought to a test examination. This is towards the inlet of the lake at the north of the cutting. It is stated as an argument here that 'Purple Slate' (*op. cit.* fig. 6, *b*; fig. 7, no. 11) occurs in contact with the felsite with no conglomerate between.[2] The section of the supposed junction is undoubtedly very difficult. We agree with Mr. Blake that both the slate and the felsite-like rock are broken, but after careful microscopic study of both varieties we have come in other respects to rather different conclusions. The purple rock certainly appears to be a variety of slate. The light-coloured one in junction-specimens is almost wholly composed of felsitic material, and might be a crushed condition of the quartz-felsite, but the relation of the two is more like that of sediments, and the darker sometimes contains bands of an intermediate character. Thus the mass is most probably an interbanded dark mud and felsitic grit,

[1] There seems in addition one negative argument which should be considered. If the thick massive conglomerate unconformably overlies Cambrian strata, nearly horizontally or with a low dip to the east, then it would be a curious coincidence that it should have been cleanly removed from over all the purple slates. So far as we know, no representative of it has ever been noticed, although extensive quarries are worked almost continuously along the east of the hill. The conglomerate-and-grit has so successfully resisted denudation at one part that it forms the thick crags of the summit, while less than 100 yards away the same resistant strata have been entirely removed.

We have to thank the owner, Mr. Menzies, for kindly giving us some interesting details relating to the slates worked in the quarries and to the associated grits.

[2] *Ibid.* p. 451.

subsequently very much compressed and wrinkled.[1] The latter fact, which seems quite clear in the three slices examined, appears contrary to Mr. Blake's view of the rocks.

The 'Purple Slate' is said by Mr. Blake to occur in mass along the lower levels only (*ibid.* p. 450).[2] The rock is partly purple and is slaty, but we fail to see any evidence which would correlate it with the purple slate of the quarries, as seems intended by Mr. Blake in his use of the term. Lithologically even, one of the most characteristic structures in the 'post-Llanberis' strata—the inter-banding of fine grit and purple slate—is certainly indicated in one part of the mass. It is followed in the railway-cutting by the beds of the synclinal, which are taken as 'post-Llanberis' (see our fig. 1, 7 *b*, 7 *c*, 7 *d*, 7 *e*, and 6, 7, 6, in map, fig. 4, p. 594), and the dip of the 'Purple Slate' (fig. 1, 7 *a*) is similar in direction to that in the northern arm of the synclinal (about 70° S.E. by E.). The southern arm, however, gives still more distinct evidence. Mr. Blake describes and draws the conglomerate, *g*, as mounting "over the back of a dyke of greenstone" (*op. cit.* p. 450, fig. 6). We find below this conglomerate a purple slaty rock or banded and cleaved argillite, indistinguishable in hand-specimens from that claimed as 'Cambrian' on the north (see our fig. 1, 7 *b*, 7 *a*). Bands similar in character also occur in the 'post-Llanberis' synclinal. Thus the supposed 'Cambrian' beds dip (at the north) with the 'unconformable' strata above, can be matched with bands intercalated among them, and appear to be reproduced to the south, turning up in that arm of the synclinal, exactly as we should expect if there were no unconformity.

The other argument used here is the distribution of the conglomerate. It is said to occur at the spots marked *a*, *c*, *g*, *m* (*op. cit.* p. 451, fig. 6), extending over different beds of the earlier series. The southern mass *m* cannot give much help. Mr. Blake, we suppose, faults it down,—we think it more probable that the rock is faulted up. The conglomerate *a*, however, is supposed to pass over to that marked *c* in the synclinal (see 3 and 7 *b* in our fig. 1, and 3 and 6 in map, p. 594). Of these Mr. Blake says "there can hardly be a doubt . . . . that [they] are parts of the same mass" (*loc. cit.*). But lithologically they appear somewhat distinct, both in hand-specimens and on microscopic examination. The conglomerate *c* has a less squeezed look than the conglomerate *a*, is more purple, and contains clearly fragments of rocks of more basic or intermediate composition, which seem practically absent from the latter. Further, the thickness of *c* is probably less than 20 feet, while that of *a* must be much greater. We believe that it is a distinct layer at a higher horizon, and it is

1 Undoubtedly a mass of felsite occurs just beyond; but, as the slate is conspicuously wrinkled, its dip can hardly be parallel to the surface of the igneous rock.

2 Again on p. 455, it is stated that 'nowhere are the felsite and Purple Slate, which are seen at the level of the railway (11, 12), to be found above.' The 'Purple Slate' is discussed in the next few sentences. But a felsite also occurs up the hill S.W. of Tan-y-pant Cottages. It is difficult on any theory to explain this outcrop, but it undoubtedly is shown in several well-marked bosses.

Fig. 1.—*Diagrammatic Section along Railway, west side of Llyn Padarn (south of the inlet of the lake), showing the junction of the supposed 'Cambrian' and 'post-Llanberis' Beds.*

[Horizontal scale (roughly) 9 yards = 1 inch.]

1 *a*. Purple quartz-felsite.
1 *b*. Probably cleaved quartz-felsite.
2. Greenstone dyke.
3. Quartz-felsite conglomerate. (Shown as 'post-Llanberis' in Quart. Journ. Geol. Soc. 1893, p. 451, fig. 6 *a*.)
7 *a*. Purple banded argillite with fine gritty laminæ. ('Cambrian,' *ibid*. fig. 6 *b*.)

7 *b*. Purplish conglomerate.
7 *c*. Crystalline grits.
7 *d*. Purplish slate.
7 *e*. Green grits, with argillite and conglomerate bands.
('Post-Llanberis,' *ibid*. fig. 6 *c*, *d*, *e*, *f*, *g*.)
8. Green banded argillite.

FF. Probably small faults.

Note.—The bands of conglomerate in 7 *e* are rather more distinct in the cliff than is shown in the diagram. Two bands occur immediately S.E. of the lines FF in the northern arm of the synclinal, and one band N. of FF. (*Cf*. G. Maw, Geol. Mag. 1868, pl. vi.)

followed by two or three still thinner,—a sequence which commonly happens.

Thus we maintain the 'opposite conclusion,' to quote Mr. Blake's own words,[1] and although we deny the identity of *b* with the Purple Slate, we do not 'miss the synclinal,' but make it more definite; and we fail to see any reason why *m* at least should not be faulted up.

Tracing the beds inland, the last-mentioned faults would account for the difference of the rocks exposed in the grounds opposite Glyn Padarn. Our observations there do not accord with Mr. Blake's. We are told that we come to grits and conglomerates which are 'corresponding rocks'[2] to those of the railway-section. The conglomerate *m* is the massive quartz-felsite conglomerate with quartzite-pebbles (3 in fig. 4, map, p. 594); but the conglomerates or pebbly bands (in the grounds) and the associated grits are, many of them, quartzose rocks containing quartz-pebbles and grains of blue quartz (11 in fig. 4, map, p. 594). This rock is similar, therefore, in many respects to the green grit with blue quartz associated with the Purple Slates[3]; and in these very masses layers of purple slate or argillite occur. Even the "large mass of purple slate lying horizontally on the top of finer conglomerate"[4] seemed to us, if we correctly identify the place, to belong certainly to one of these bands. It is not, therefore, a fragment derived from any possible underlying rocks, and so no proof that the series is 'post-Llanberis' in age.

Mr. Blake says: "If we pass along an E.N.E. to W.S.W. line . . . we cross a definite succession." It is not easy to recognize this definite succession. Compact grits are followed by a coarse green pebbly grit with bands of conglomerate and of argillite, but beyond the wall this runs on the west right up to the slate tips; the grey slate outcrop being nearer the quarry. It is further stated that this succession has "a gentle dip towards the E.N.E." and that "we have here a series . . . . nearly horizontal." Some of the dips which we noticed are obscure, but three are clear:—to N.N.W., to N.W., and to N. of W. at 30°, 18°, and 30°; while one dip to S.E. at 32° appears to be due to a synclinal roll.

The description of a regular series takes no account of any faults, but one at least (probably two) can be traced across the neighbouring slate-quarry.[5] The apparent interruption of this slate may be due to another line of fault roughly north-easterly, for, as we have stated, a fault is seen (or rather parallel faults) on the railway-section near the continuation of the line of junction.[6]

[1] *Op. cit.* p. 452. [2] *Ibid.* p. 453.

[3] A green grit, containing similarly blue, purple, and red quartz-grains, is characteristic of certain bands in the Harlech and Barmouth areas.

[4] *Ibid.* p. 453.

[5] This may be partly the cause of some variation in the dips and outcrops nearer the road.

[6] These are shown in the section given by Mr. Maw (Geol. Mag. 1868, pl. vi. and p. 121), from which our drawing differs in some minor details. We have not, however, thought it necessary to give a separate diagram, as we believe that Mr. Maw's drawing correctly represents the important points of the general succession, except in the matter of the unconformity.

Mr. Blake speaks of it there as a 'slight fault,' but it is so only on his own hypothesis; to argue from that statement is reasoning in a circle. This 'slight fault' is supposed to account for the grit and conglomerate being carried down to the railway-level; while at the higher ground they are "all but actually *seen* to overlie [the Purple Slates] unconformably" (*op. cit.* p. 454).

We have discussed the grounds for this view, drawn from the lithological succession and the dip. The remaining argument, as given by Mr. Blake, is: "if I understand rightly the section given by Mr. Maw . . . . it runs beneath these very grits and conglomerates." But, apart from the fact that that section represents conglomerate under purple slate, there is a serious misunderstanding, for the adit described begins about 80 yards away from these grits, since it extends from the second to the third Glynrhonwy Quarry.[1]

Passing to the north-west, we cannot agree that the conglomerate can be traced 'step by step from 13 by 14, etc., to 19' (*op. cit.* p. 455). It can be traced from 13 nearly to the streamlet which comes down (past Tan-y-pant) to the corner of the inlet of the lake, but—as we believe—not beyond (3 in our map, p. 594). The conglomerates south of the streamlet appear to represent the—probably thinner and higher—bands of the railway-section (6, etc., in map, p. 594). Along the boundary next the felsite, we are told that the conglomerate behaves as an unconformable deposit. The variation may be due partly to faulting, partly to the occurrence of interchangeable deposits of grit and coarser material, much as the local sandy and pebbly beaches of the present day. But the important outcrop is the 'knob of hard Purple Slate' intervening between felsite and conglomerate. The few such knobs as we saw appear to be part of the purple banded series occurring on the hill,[2] and do not separate the felsite from the conglomerate. At the place (21)[3] marked by Mr. Blake as proving the existence of 'Cambrian' slate, we find the outcrops[4] next the felsite to be, firstly a cleaved, rather coarse grit somewhat resembling a 'rain-spot' breccia, then a purple quartz-felsite grit with pebbles, a purple banded grit and argillite, greenstone, then purple grit, after which the quartz-felsite conglomerate reappears (see map, p. 594).

Then we turn to the 'associated rocks' and the evidence of their lamination. Mr. Blake says that "almost wherever seen these laminæ, etc., are horizontal . . . . a circumstance which first excited my

[1] We have to thank W. Roberts, Esq., the manager of the Glynrhonwy Slate Quarries, for very kindly giving us this and some other information in answer to our enquiries. He mentioned also, what seemed to us a point of some interest, that the goodness of the slate appeared to depend on the occurrence of an adjoining mass of grit ('granite' of the quarrymen).

[2] Included in Mr. Blake's map in the symbol 'Post-Llanberis conglomerates and grit,' fig. 7; also fig. 2. This inclusion of things so different as coarse conglomerate and banded slaty and gritty rocks under one symbol makes Mr. Blake's maps difficult to follow, and likely to mislead an observer unfamiliar with the ground.

[3] *Op. cit.* p. 452, fig. 7.

[4] At the parts measured by scale on the map.

suspicions that they were not what they had been taken for."[1] In an area extending for about ¼ mile "above the road from the Glyn Peris Hotel to the commencement of the felsite," passing Tan-y-pant, some roughly horizontal outcrops occur,[2] but fourteen dips more or less trustworthy were measured, out of which not one was horizontal, very few were gentle dips, the average was from 30° to 35° or 40°, and two at least indicated high angles of 50° and 70°.[3]

We have not worked over all the details farther up the hill, but until some distinction is drawn between different grits and conglomerates no inference from isolated outcrops can be trusted. Certainly the specimens at one part from near Cefn Du quarries, lithologically, are similar to the quartz-grits which are found among the workable slates, and are very different from the great quartz-felsite conglomerate. If slate-holes were found on different sides of this grit,[4] this would be no more than might have been anticipated.

IV. East of Llyn Padarn: Inland Sections.

Along the eastern boundary of the series of conglomerates, etc., Mr. Blake's map is misleading, even according to his own description. As he says, the conglomerate *i* resembles *a*, yet he marks it by a different symbol (*op. cit.* p. 447, fig. 2). It is with this conglomerate, *i* (3, near the Boat-house, in our map, p. 594), that we have to correlate various outcrops north of Mr. Blake's 18, west of the felsite on which 24 is marked, while the so-called 'Banded Slates' (*g–h*, *op. cit.* fig. 2, 'Cambrian') are many of them lithologically indistinguishable from—and can be traced along to—the banded gritty series of the east of Y Bigl marked as 'post-Llanberis' (see our map, 5, 6, 7, p. 594).

A further argument is based on the stratigraphy of Moel Goronwy (Moel Gronw). Mr. Blake states that the felsite of this hill differs from that of Clegyr in being more compact.[5] We think it would be an improvement to substitute 'less' for 'more,' but the difference is trifling and the former rock agrees in its general character[6] with the ordinary felstones of the neighbourhood, displaying a fluxional

[1] *Op. supra cit.* p. 455. It is impossible, we find, to be sure of the exact outcrops indicated by the numbers on Mr. Blake's maps; but the area examined here extended beyond '18, 16, 10,' the points to which he especially referred.

[2] At some spots small synclinals or anticlinals seem indicated.

[3] Other dips not so well exposed were measured, and many more were noticed. Some variation in the dips doubtless is due to the intrusive greenstone. The whole hill very possibly is underlain by a large mass, which may occur like a laccolite, and certain of the strata are baked and changed to porcellanite. Some knobs of hard purple slate occur, which evidently are parts of the banded series altered in this way. The general dip in the part towards the felsite is to a north-westerly point, but south of the Tan-y-pant streamlet the direction is changed.

[4] *Op. cit.* p. 455.

[5] *Ibid.* p. 450.

[6] One slide of the rock includes many small crystals of secondary minerals, some being white mica, others probably a carbonate. But similar minerals occur in the main mass of the felsite.

structure equal to that of Cwm-y-glo, and enclosing lumps of a compacter and redder felstone,[1] as the principal mass does near Bettws Garmon. Although the massive conglomerate of the western is wanting on the eastern margin of the igneous rock of Moel Goronwy, yet the felsitic grits with occasional seams of quartz-felsite pebbles[2] indicate a similarity of material (4 in our map, p. 594). But the existence here of a fault seems highly probable from the nearness of the outcrop of purple slates, from the absence of the main mass of the conglomerate, and from the variation found along a continuous line down to the lake. On the railway Mr. Blake states that there is possibly a fault, but makes no allowance for its continuance at Moel Goronwy.

Tracing next the outcrops along the western boundary of the conglomerates, etc., the most important argument is the sudden change at the north of the quartzite-conglomerate (11, 12), which, if the map given by Mr. Blake were accurate, could be explained only by more than one fault. But instead of the rocks east of the line 25 to 11 in his map being rightly represented by the same symbol as the great quartzite-conglomerate, they require a different sign, and the difference between the rocks east and north of 11—that is, between 'post-Llanberis' and 'Cambrian'—does not exist. The same purple and grey-weathered, finely laminated and banded grit and argillite (which we should describe as of Y Bigl type) occurs, followed to the eastward in each case by green banded slaty rocks and grits, like those on the summit of Y Bigl. If the fault which Mr. Blake marks on the railway (*op. cit.* p. 445, fig. 1, between *a* and *x*) is continued inland,[3] it would account first for the conglomerate, then for the felsite, coming into close association with the banded gritty or slaty rocks (see F^2 in our map, p. 594, south of Tyddyn Du, 3, 1, and 7).

Between the two boundary-lines the rocks of the slate-railway section strike towards the slopes of Y Bigl. On this hill several examples are noticed, and two are drawn representing grits overlying Pale Slates (*op. cit.* pp. 448, 449, figs. 3, 4). We were not satisfied as to this interpretation for the one which we visited, but as the horizon of these beds is part of the point in dispute, the sections would only supply an argument for an unconformity to an observer who already is convinced. We are also told of the difference between all these rocks of Y Bigl and those of the railway syncline. As we shall show, the latter include some banded grits and conglomerate, such as occur over the higher slopes. It is, however, true that here on the hill the pale banded slates of the railway do not seem to extend over a wider area, as should happen in a section of a syncline,

[1] Sir A. Geikie has called attention to both these characteristics, Quart. Journ. Geol. Soc. vol. xlvii. (1891), Pres. Addr. *Proc.* p. 94.

[2] These apparently are the 'curious breccias derived from the felsite,' to account for which, on his hypothesis, Mr. Blake has to suppose the Moel Goronwy felsite a later eruption, *op. passim cit.* p. 450.

[3] The fault which has been suggested by one of us as occurring between the felsite and the conglomerate was not supposed to be great, and might have died out in a short distance from the lake.

made by gradually rising ground. But if the axis of this syncline sloped to the south-west at an angle of about 12°,[1] the lower strata of grit, etc., would spread over a broader tract. Is, however, the pale slate completely absent from the summit of the hill? It seems to us that it does occur (probably over a limited area), and that although the rocks show varietal differences, there is no strongly marked lithological distinction.[2]

Mr. Blake's hypothesis moreover only seems to substitute another and rather greater difficulty. If the Moel Goronwy felsite overlies in succession the Banded Slates, what has become of the syncline which admittedly has extended from the railway for nearly ½ mile to Y Bigl, and then has died out in less than 300 yards? Or, if the syncline is continued, then the Moel Goronwy felsite must be separated from the Banded Slates by a fault. Then what has become of this fault at the railway? (Compare fig. 5, p. 597, *postea*.)

The strata of Y Bigl also are said to be horizontal, and this, if true, would be strongly against the view that they belong to the railway succession.[3] The same position is exhibited in Mr. Blake's fig. 5 (*op. cit.* p. 449).[4] As no dips are given on the map (away from the lake), we were unable to verify the particular observations on which the statement was founded, but the amount of the dip was measured at some twenty places[5] lying within Mr. Blake's 'post-Llanberis' area on Y Bigl. Of these observations, in one the crumpled laminæ maintain a roughly horizontal direction,[6] in all others the dips were not less than 35°, and in more than half they were as much as 50° or higher.[7] And these are the beds whose horizontal position proves the unconformity!

V. East of Llyn Padarn: Alleged Unconformity on the Slate Railway.

In the previous instances the evidence is indirect, but at one spot we are told that the hypothesis can be brought to a direct test.

[1] A greater slope than this is indicated at Yr Allt Wen in the Survey Memoir, fig. 64, p. 181.

[2] Specimens have been examined under the microscope and they show a certain amount of family likeness, particularly in the coarser bands. In each, but especially in two specimens from the syncline of the railway, several rather angular fragments of the dark rock (described *infra*, p. 598) occur, which generally are abundant in Mr. Blake's 'post-Llanberis' group.

[3] An argument in support of this view may be drawn from the strike which can be traced in certain distinguishable layers as roughly to north-eastward; that is, agreeing in direction with the outcrops indicated in the railway section.

[4] This section is difficult to understand, unless we are to suppose that a fault, throwing down the 'post-Llanberis' conglomerate at the N.W. end, ran opportunely along the nearly vertical junction of the felsite and the banded slates. But even so, the latter must have rested on the former and have been afterwards curiously twisted up just on the southern side of the fault.

[5] These were the clearest exposures. The dips were noticed at many other outcrops.

[6] At a place which we believe may be on the line of the anticlinal from the lake.

[7] Here also, as at Moel Tryfaen, these measurements are sometimes less than the true dips. See p. 580.

To this must be the final appeal. Mr. Blake maintains that by the side of the slate-railway east of Llyn Padarn, his 'post-Llanberis' conglomerate can be seen unconformably overlying the beds which are admittedly Cambrian. This is at the spot originally described by one of us[1] as the second of the three masses of conglomerate (numbered 3, 6, and 3, in our fig. 2, p. 590, and in our map, p. 594). It is a thinner mass, as was then noticed, and it also differs somewhat lithologically from the first and the third, so that, from these reasons, and from careful tracing of the dip in the associated beds, we now incline to think this second conglomerate may be a different and slightly higher band.

In the original diagrammatic section along the railway given in the description referred to above, the synclinal and the anticlinal were shown. At the latter part Mr. Blake introduces a fault, and we (though partly for different reasons) think that one probably is present; but we do not agree with him in thinking that "there is no anticlinal" (*op. cit.* p. 446). We still adhere to the original diagram, but should shift the position of the anticlinal axis in it southward, so as to fall nearly on the third conglomerate[2] (3 in fig. 2, p. 590; and 3, near Boat-house in map, p. 594). Again and again, in the little crags just above the railway, the dips are well exposed—towards a north-westerly point on the one side, towards a south-easterly point on the other side of a line which is thus clearly anticlinal.

We are told, however, that the unconformity is distinctly proved at one place, and it is drawn as shown in Mr. Blake's fig. 1 (*op. cit.* p. 445). A conglomerate *A* lies unconformably upon the slate-breccia *g*, and Mr. Blake states that Prof. Green, Sir A. Geikie,[3] and himself have recognized the difference, "which others have failed to do." Even the latter statement is incorrect, for one of us called special attention in 1879 to the fact that the section shows conglomerate and a sort of 'rain-spot' rock underlying the conglomerate.[4] In the conglomerate, as shown in the cliff-section, the pebbles are rounded or subrotund, larger, and fairly close, but with a finer gritty matrix between.[5] The upper part is weathered, and this causes the pebbles therein to stand out in relief, but they are present equally in the lower unweathered part, the two clearly forming a single mass. The underlying 'rain-spot' rock is more strongly cleaved, as stated by Sir A. Geikie. This character, however,

[1] T. G. Bonney, 'On the Quartz-felsite and Associated Rocks at the Base of the Cambrian Series in North-western Caernarvonshire,' Quart. Journ. Geol. Soc. vol. xxxv. (1879) p. 309.

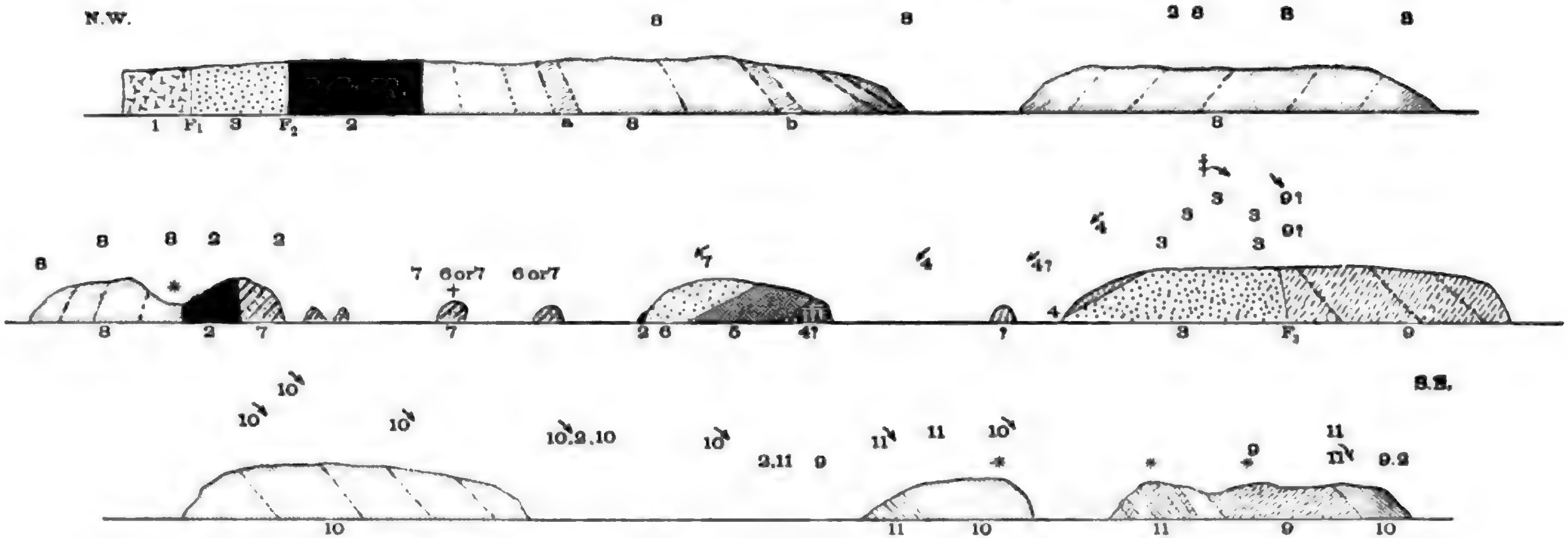
[2] The greater thickness of the third conglomerate might be due, partly at least, to the anticlinal roll. Some, however, of the first conglomerate might be cut out by the fault which limits it on the south.

[3] Sir A. Geikie, however, does not admit the existence of the unconformity. Quart. Journ. Geol. Soc. vol. xlvii. (1891) Pres. Addr. *Proc.* p. 95, note.

[4] 'A sort of 'rain-spot' rock at the base of the middle mass,' T. G. Bonney. *op. supra cit.* p. 315.

[5] The pebbles are not unusually 1½" or 2" long by 1½" broad, but most commonly from ½" to ¾". In the 'rain-spot' rock the fragments are smaller and more elongated along the cleavage.

Fig. 2.—*Section along Slate Railway, east of Llyn Padarn.*



1. Quartz-felsite.
2. Greenstone dykes.
3. Conglomerates, supposed identical.
4. Felsitic grits. (The nature of 4 ? is doubtful; the block to the S. marked by a simple ? may not be *in situ*.)
5. 'Rain-spot' breccia.
6. Conglomerate.
7. Purple banded grit and argillite, sometimes conglomeratic or approaching breccia; seemingly related to 6.
8. Banded argillites and fine grits. At *a* and *b* a kind of 'rain-spot' breccia and a grit.
9. Massive green grits. (We are not quite certain whether the most northerly mass is quite the same as the more southerly beds.)
10. Purple Slate.
11. Rocks like 9 and 10 interbanded.

F¹. Probably a small fault.
F². Dyke in line of fault.
F³. Junction obscure, probably a fault.

* Quarries.
† This mass shows an ascending succession of (*a*) purple banded grit and argillite, (*b*) breccia, (*c*) purplish grit.
‡ A grit, probably related to 4, but with some resemblance to 7.

The lines of shading are not intended to represent the direction of the dips: these are roughly indicated by the stronger lines shown at intervals in 8, 9, 10, and by the lines in 7. The figures placed above the section indicate approximately the position, on the hillside, of outcrops of the rock which the numbers express; the dip is in the general direction of the arrows.

[Horizontal scale (roughly) 22 yards=1 inch.]

is still more clearly marked in the banded grit and argillite, which occur above the rounded conglomerate. That the upper conglomeratic part was deposited continuously on the lower breccia is proved by the finer matrix graduating from the one to the other. This is seen unmistakably both in the cliff and in a microscope section cut from a junction-specimen.[1]

Not only, however, is the unconformity quite disproved, but the only line which might be supposed, and has been supposed (by Prof. Green), to mark it is not shown by Mr. Blake. His drawing improves on the earlier sketch by altering the actual line to a non-existent division. The conglomerate is not mast-headed on the top of the lower part of the cliff as shown by him. The line of separation is not a 'nearly *horizontal* line.' It more closely approaches that position just at its southern end, but soon curves and slants down to the railway, as is shown roughly in Prof. Green's drawing, and with a little more detail[2] in the sketch on the following page (fig. 3).[3]

We are told, however, not only that there is a 'nearly *horizontal* line of separation,' but also that in the underlying rock 'different *vertical* sheets' have different characters.[4] The 'nearly horizontal line,' as already stated, does not exist, neither do the 'vertical sheets.' Mr. Blake says that the conglomerate (which we prefer to call, for the sake of distinction, the 'rain-spot' breccia) is 'vertically bedded.' It has, indeed, a roughly vertical cleavage, but of stratification in this direction we could see no evidence. It is stated that it changes "in a horizontal direction to more and more felsitic material till it is almost a felsite or pure felsitic ash." Lithologically we should not object to this description, but the first distinct change, passing from the 'rain-spot' breccia to the southward, seems marked by a line dipping north-westerly at a moderate angle (about W.N.W. 35°), which hardly can be considered to mark a 'vertical sheet.' Also, in the underlying felsitic rock (which possibly may be a squeezed grit[5]), a band seems indicated (although indistinctly) showing a similar dip. Thus the dips in the section roughly agree: namely,

[1] In this slide an infiltrated mineral seems to us to be a kind of opaline silica. Other slides prepared from Mr. Blake's 'post-Llanberis unconformable conglomerate' *A* show that the materials are of the same character as those in the underlying breccia, and different from the conglomerates *a* and *i* with which he classes it.

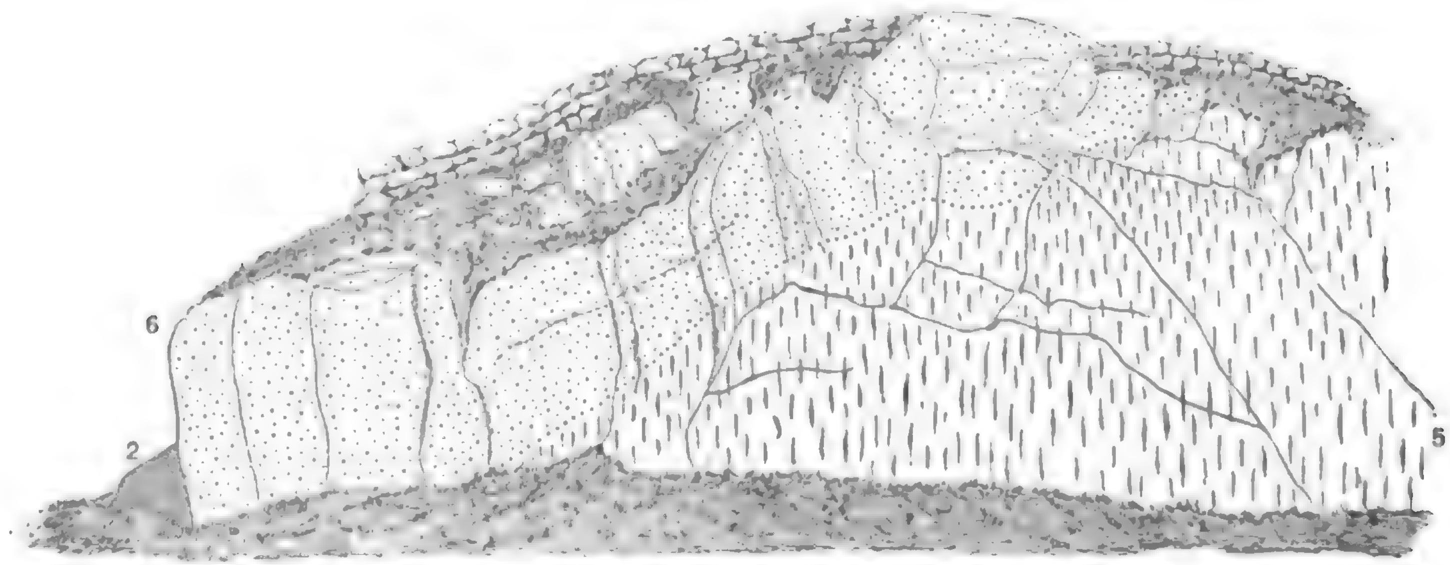
[2] From drawings made on three separate occasions by two different observers.

[3] It seems, then, since Mr. Blake himself has not succeeded in correctly representing the cliff, that my words—'the section is not so clear in nature as in the diagram'—were not unjustifiable after all.—T. G. B.

[4] It must be remembered that the bands originally supposed to denote vertical layers of slate proved on examination to be thin dykes of compact diabase, C. A. Raisin, Quart. Journ. Geol. Soc. vol. xlvii. (1891) p. 333.

[5] This rock is so much affected by pressure and micro-mineralogical changes that it is very difficult to determine whether it has been originally a felsite or a felsitic grit. In an earlier description by one of us it was regarded as possibly the former faulted up, but we now incline, though with hesitation, to the latter view. [Also, even if a faulted junction occurs, I doubt whether the line of it is visible, as was formerly suggested.—C. A. R.]

Fig. 3.—*The alleged unconformity.* *By the Slate Railway, eastern side of Llyn Padarn.*



2 = Greenstone. 5 = 'Rain-spot' Breccia. 6 = Conglomerate.

[The dotted line indicates the junction of the breccia and the conglomerate. Above the higher broken line in 6, the weathering of the upper part of the conglomerate is more than usually conspicuous. It must be remembered that the drawing is necessarily to a certain extent diagrammatic, and that the rocks are distinguished by conventional symbols.]

that in the so-called line of unconformity, that above it, and that in the possible banding below it.

The alleged unconformity, therefore, seems not only unsupported, but also actually contradicted by direct evidence. If further proof were needed, it would be found in the continuation of the section northward and southward. The dips in both directions and the lithological characters give some evidence. On the north Mr. Blake marks 'greenstone or green grit not properly examined' (*op. cit.* p. 445). We find here a greenstone which is partly compact, partly porphyritic, and grits (2 & 7 in our fig. 2; see also map, p. 594). The grits are distinctly banded, and continue the succession above the conglomerate, with purple argillite-laminæ of the typical interbanded character. In addition, some bands show distinctly the 'rain-spot' breccia-type, proving the recurrence of this same variety above the supposed unconformity.[1]

We have discussed this section at some length, because it is the place of which Mr. Blake states that he 'cannot imagine a more satisfactory proof of unconformity in a single section' (*op. cit.* p. 446). If unconformity there be, we have never before seen one so successful in concealing itself.

VI. Stratigraphical Succession.

Here, perhaps, a short summary may be given of the explanation which we venture to suggest for some of the sections described above.

On the west of the lake the conglomerate next the felsite (and largely derived from it) extends above the road above Tan-y-pant, followed by a grit of similar material. Still higher up on the hill, interbanded grit and argillite occur, with pebbly layers and a kind of 'rain-spot' breccia. The oblique direction of the outcrop of these beds, and their general dip to a north-westerly point, *i. e.* towards the felsite, indicate the probability of a line of fault along the boundary of the igneous rock (F^4 in map, p. 594), as was formerly suggested by one of us.[2]

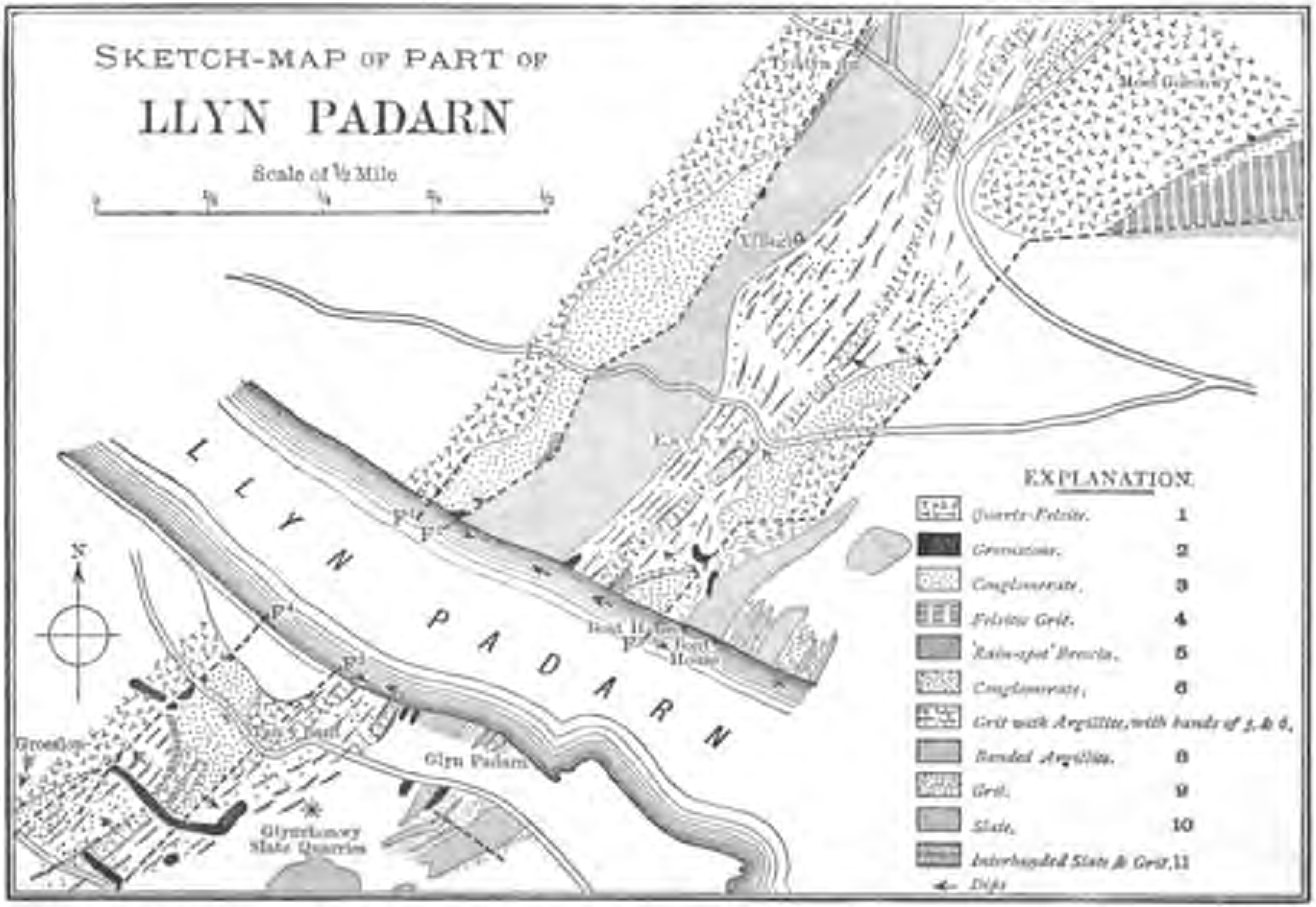
The conglomerate, however, and other beds are abruptly terminated near the little streamlet already mentioned, beyond which a sudden change of dip is found, so that this also seems to be a parallel line of fault (F^5 in map).[3] By it the reappearance of the felsite towards the lake may be explained, as well as the crushed and schistose condition of some of the rock in the small 'stream quarry.' But this fault makes it more difficult to come to a

[1] Bands more or less similar occur at other places—in the syncline by this railway, on the railway west of Llyn Padarn, and on the hill above Tan-y-pant.

[2] T. G. Bonney, Quart. Journ. Geol. Soc. vol. xxxv. (1879) p. 314. This fault might account for the true felsitic conglomerate reappearing in small exposures near Groeslon, and for the crushed condition of other beds near.

[3] A fault roughly near this seems to be marked on the Geological Survey map. Possibly another parallel fault occurs, bringing up the felsite N.W. of this, already mentioned. See note, p. 582.

Fig. 4.



[Arrows indicate the general directions of dip.—Broken lines mark the probable direction of the more important faults.]

conclusion as to the exact position of the purple felsite which has been described by Sir A. Geikie.[1] If we may infer from its high southerly dip that it is an interstratified band on the S.E. side of the fault, then, as Sir A. Geikie believes, it probably would be a small lava-flow higher in the succession than the great quartz-felsite, from which it differs lithologically. If, however, it be on the northern side of the fault, this difference would lead us to suppose it to be an external part of the lava-flow. At parts it has remained uncleaved, and this is especially the case in an outcrop well shown (in a dry season) at the edge of the lake. We have already dealt (p. 585) with the alleged junction of felsite and 'Cambrian slate' in the crag nearly between these two localities.

Neither of the faults before mentioned is great, not so large as many of the parallel displacements among higher strata which are shown in the Geological Survey memoir and map.[2] Beyond the stream fault, the interbanded argillite and grit probably belong to the syncline which is well marked, along and above the railway, by bands of purplish conglomerate. The next cutting through bastard slates and greenish grits, which, owing to undulations, extend for some distance, though they have proportionally a rather small thickness, exhibits not a few faults, so that probably the general result has been to let down the whole mass in a kind of trough. Unless this be so, these beds can hardly be equivalent to the green banded hälleflinta and grit on the east of Llyn Padarn. The rock adjacent to the conglomerate (south of the bridge in Glyn Padarn grounds) is slickensided and the junction probably is a faulted one. This conglomerate, as we have said, may be the representative of

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[NOTE TO MAP.—A few outcrops in this area have not been visited, and others need re-examination to test the hypothesis here represented.[3] Further, many variations occur (not possible to show on this map), apparently due partly to small faults or rolls, partly to the slope of the synclinal or anticlinal axis. This axis seems to dip with the slope of the hill, sometimes at a less angle. Also the different layers mentioned above are not always sharply distinct, gradations occurring between them, which would be expected, if (as the Authors believe) the rocks form a continuous series. The Authors are fully aware of the defects of the map, but they nevertheless insert it, since, notwithstanding its imperfections, it may be of use to make parts of the accompanying paper more easily understood.]

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[1] Quart. Journ. Geol. Soc. vol. xlvii. (1891) Pres. Addr. *Proc.* pp. 96, 97.

[2] The stream fault, apparently the greater, might have a throw of 140 feet; but such an estimate is purely hypothetical.

[3] Thus beyond the road south-west of the Moel Goronwy felsite (although part is grassed over) conglomerates are exposed, and possibly they include some representative of conglomerate 3, in which case its outcrop might extend continuously to the west of Moel Goronwy.

At * the ground is largely covered with slate tips, and is partly grass, with some outcrops of grits, etc.

that next to the felsite, which lithologically it seems to resemble. In that case the fault probably would be as great as that north of the section east of the lake, while the throw of one to bring in the Purple Slate would have to be rather greater.[1]

North-east of the lake the following seems to be the general succession of the beds:—(*a*) a lower conglomerate mainly derived from the quartz-felsite, often containing also some pebbles of quartzite and granitoid rock (3 in fig. 2, p. 590); (*b*) a grit of similar materials (4 in fig. 2); (*c*) coarse strata, including fairly numerous fragments of somewhat basic igneous rock,[2] as in the 'rain-spot' breccia, the overlying conglomerate, and other pebbly bands (5 and 6 in fig. 2); associated grit of similar composition interbanded with argillite (7 in fig. 2); (*d*) green banded finer grit, hälleflinta, and argillite and purplish fine-grained rocks (8 in fig. 2), leading up to the Purple Slate. These last indicate the beginning of the continuous quiet deposition which characterizes so much of the Cambrian period. They appear to be associated with the green grits containing coloured quartz-grains, as already described.

In lithological character the third (or southern) mass of conglomerate in the railway-section seems to be similar to the first or northern. As already described, the dips above the third conglomerate indicate an anticlinal, and thus the grits, conglomerate, and banded series on the north may be taken as higher beds. If so, they are probably cut out to the north-west of the synclinal of green banded rocks, and to the south of the third conglomerate, by two faults, both of which are admitted by Mr. Blake (see F^2 and F^3 in our map, p. 594). Probably the fault between the felsite and the conglomerate (F^1) is small, but that along which the greenstone is intruded on the south of the western conglomerate (F^2) is greater, for it apparently cuts out beds 4, 5, 6 (figs. 2 and 4), perhaps a little of the upper part of 3, and some of the lower part of 7.

We believe that the anticline of the railway-section is indicated to the N.E. at various spots[3] towards the Moel Goronwy felsite, and

[1] Possibly the first might be 400 feet, the second (still more difficult to estimate) 600–700 feet. But the fault at Nantlle is described by the Geological Survey as throwing the slate directly against the quartz-felsite.

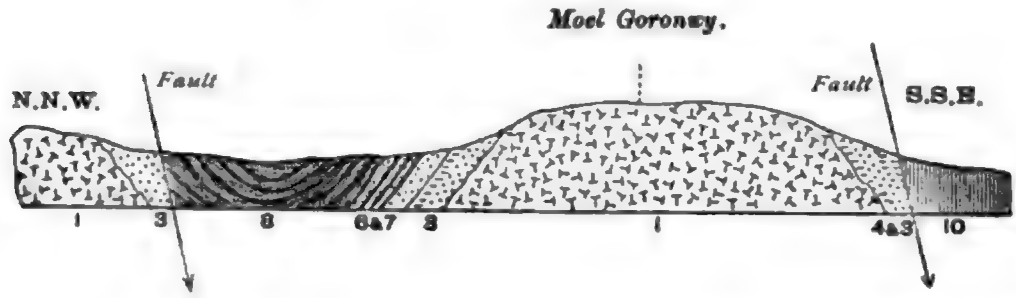
[2] Probably similar to those mentioned by Sir A. Geikie (Quart. Journ. Geol. Soc. vol. xlvii. 1891, Pres. Addr. *Proc.* p. 96). We do not, however, see that there is proof of the contemporaneous ejection of these. It is difficult to conceive them as the ejectamenta of expiring volcanic eruptions, since they are different from any of the larger masses of igneous rock in the neighbourhood—unless, indeed, certain more distant rocks of similar composition (such as those in the Lleyn) could be proved to belong to this age.

[3] At more than one place a close resemblance can be traced to the banded grit south of the third conglomerate on the railway, dipping south-easterly, and other dips to the north-westerly point are exposed. Between the two roads which join to the eastward at the School, a curious purplish rock occurs, and also a more normal-looking purple felsite (possibly a dyke—we have not examined its relations). The former shows in places a clean-welded junction with a greyish felsite and exhibits a structure like a flow; it even runs in among fragments of the felstone. Both rocks have been affected by subsequent pressure. The purplish rock rather reminds us of a specimen described by one of us from Baron Hill Park, near Beaumaris (T. G. Bonney, Quart. Journ. Geol. Soc. vol. xxxix. 1883, p. 472).

in the dip of some of the beds to the west of that hill. We notice that even the map given by Mr. Blake (*op. cit.* p. 447, fig. 2) would be more easily interpreted on our hypothesis (fig. 5 below).[1]

In attempts to connect the readings on the two sides of the lake, we find there is a general correspondence. A double fault seems indicated near the felsite on both railways, the throw being greater on the north-east of the lake. It appears possible that the small

Fig. 5.—*Section across Moel Goronwy, illustrating the probable relations of the beds mapped in Quart. Journ. Geol. Soc. vol. xlix. (1893) p. 447, fig. 2.*



1. Quartz-felsite.
3. Conglomerate.
4. Felsitic grit.

6 & 7. Purplish conglomerate and grits, passing up into banded argillite.
8. Banded argillite.
10. Purple Slate.

NOTE.—The conglomerate north-west of the Moel Goronwy felsite appears to resemble conglomerate 3 in our figs. 1, 2, and 4. The mass shown N.W. of the synclinal has not been examined by us, so that its similarity is merely inferred from the stratigraphical relations.

syncline on the south-west might be equivalent to the beds occupying the wider curve on the opposite shore ; more probably, however, all the undulating beds on the former side are faulted representatives of the latter. But the want of exact agreement, together with the fact that the beds on the rising ground on each side seem to dip towards the lake, suggest that a fault may very likely extend along the line of the lake itself. Such a line of disturbance is shown on the Geological Survey map in the upper part of the valley.

VII. Comparison of Microscopic Sections.

We have further examined microscopic slices of many typical specimens. The following brief summary of the details and of our

[1] This must be considered hypothetical, until further examination is made and the dips are recorded. We have only partially examined the section, but it seemed to us that a succession was indicated in the conglomerates and grits, which would agree with our interpretation of the outcrops to the S.W. and of the section by the lake.

conclusions is limited to rocks from the locality of Llyn Padarn[1], which Mr. Blake has definitely grouped with one of his two series.[2]

I. In the conglomerates or breccias of rather basic materials, taking specimens from critical parts on both sides of the lake,[3] we find these to consist of fragments of the following:—

(*a*) Ferruginous andesitic or basaltic rocks, recalling sometimes the character of masses described from the Lleyn. They include
1. Fragments, where lath-shaped felspars, clear, but replaced by an aggregate of minute minerals, are embedded in a continuous black opaque ground;
2. Fragments, where similar felspars occur in a ground speckled with opacite;
3. Fragments, with a felsitic cryptocrystalline ground, rich in ferrite.

Some of these fragments may represent lava with flow-structure.

(*b*) Andesitic fragments, containing viridite or chlorite within crystals or in the groundmass: including
4. Ferruginous rock with some viridite;
5. Rock with a matrix of viridite, perhaps originally a kind of tuff.

(*c*) 6. Andesite or felsite, deficient in iron oxide and viridite.

[1] Many more slices have been examined, and reference to other districts, or to slices from other rocks in this district, would rather strengthen the case, but it would extend the statement to too great a length. We may, however, add that we have compared the slices of grits and conglomerates from Mr. Blake's 'Cambrian' and 'post-Llanberis' beds in the neighbourhood of Llyn Padarn with a number of those from the area between Brithdir and Bangor (Tairffynon, etc.). Though varietal distinctions exist, to some of which attention has been called in former papers, these beds on the whole bear a general resemblance to the clastic rocks discussed in the present communication, and the lava-fragments occurring in the one set can often be identified in the other. Hence it is more probable that all belong to one and the same period than that they represent two periods separated by a vast physical break.

Mr. Blake, in an earlier paper (Quart. Journ. Geol. Soc. vol. xlviii. 1892, pl. vi.), admits the conglomerate north of Llyn Padarn to be the equivalent of the Bangor Conglomerate. (It is also referred to by one of us, C. A. Raisin, Quart. Journ. Geol. Soc. vol. xlvii. 1891, p. 335.) To us, however, the former seems very similar to the conglomerate immediately south of the main mass of felsite on both sides of the lake, which he claims as 'post-Llanberis.'

[2] The specimens were not directly cut to establish this comparison, so that the preponderance of any one group on one or the other side of the lake is often accidental. The references give the localities of the specimens as marked in Mr. Blake's figures and maps as nearly as is possible, Quart. Journ. Geol. Soc. vol. xlix. (1893) pp. 441 *et seqq.*

[3] A.—East of Llyn Padarn by slate-railway, 'rain-spot' breccia underlying supposed line of unconformity. Figs. 1 and 2, *g*. 'Cambrian.'

B.—East of Llyn Padarn near road north of Fachwen. Fig. 2 about N.W. of F in Fachwen. 'Cambrian.'

C.—East of Llyn Padarn by slate-railway. Conglomerate overlying supposed line of unconformity. Figs. 1 and 2, *A*. 'Post-Llanberis.'

D.—East of Llyn Padarn. Ditto. 'Post-Llanberis.'

E.—East of Llyn Padarn, to south-eastward of the top of Y Bigl. Fig. 2, ? about due S. of 23. 'Post-Llanberis.'

F.—West of Llyn Padarn, hillside above Tan-y-pant. Fig. 7, ? about due N. of 16. 'Post-Llanberis.'

There are gradations, and no absolute separation exists between the above-named groups, but the fact that these merely minor varieties recur in rocks at different horizons is a very strong argument for the view that denudation was proceeding continuously. We find all the six types of material present in rocks below and above the supposed break. Four of the varieties can be recognized in every slide examined, and five in nearly all the sections. There are also other points of likeness in the structure of the fragments, such as slight varieties of fluxional, scoriaceous, and other more microlithic structures. All these characters are common to the 'earlier' and the 'later' series.

In certain finer-grained clastic rocks, where bands of grit alternate with more compact layers, the materials are evidently of similar character, although the recognition of minor varieties cannot be so complete as in the case of larger fragments, and fewer slices have been prepared from what necessarily would be a less interesting series. Fragments, however, can be recognized of the above-mentioned types (*a*) and (*b*) in slices from 'Cambrian' and from 'post-Llanberis' rocks, while some of the structures mentioned are reproduced; the finer material also is of the kind which would be formed by the further wear of similar masses. Thus these banded rocks can be recognized microscopically (as we have previously shown that they can macroscopically) both above and below the supposed break.[1] Also they grade into the coarser as well as into the finer layers, and thus form part of a continuous series.

The still finer gritty or banded argillites cannot, of course, afford much direct evidence. Still, those assigned to the two ages have a general similarity, especially noteworthy in the seams rich in angular fragments of felspar and quartz, and both frequently present resemblances to the groundmass of the aforenamed coarser rocks.[2]

Taking, lastly, rocks formed of more acid material, the frag-

[1] G.—East of Llyn Padarn. Slate Railway. Figs. 1 and 2, *f*. 'Cambrian.'
H.—West of Llyn Padarn. Hillside above Tan-y-pant. Fig. 7. 'Post-Llanberis.'
I.—West of Llyn Padarn. Ditto.

[2] J.—West of Llyn Padarn; near inlet of lake. Figs. 6, *b*; 7, No. 11. 'Cambrian.'
K.—East of Llyn Padarn, from syncline by slate-railway. Figs. 1 and 2, *d*. 'Cambrian.'
L.—East of Llyn Padarn, from syncline by slate-railway. Figs. 1 and 2, *c*. 'Cambrian.'
M.—East of Llyn Padarn, from syncline by slate-railway. Figs. 1 and 2, *b–d*. 'Cambrian.'
N.—East of Llyn Padarn, from syncline by slate-railway. Figs. 1 and 2, *b–d*. 'Cambrian.'
O.—East of Llyn Padarn, near the top of Y Bigl. Fig. 2. 'Post-Llanberis.'
P.—East of Llyn Padarn, near top of Y Bigl. Fig. 2. 'Post-Llanberis.'
Q.—East of Llyn Padarn, about S.W. of the top of Y Bigl. Fig. 2. 'Post-Llanberis.'
R.—East of Llyn Padarn, about S.E. of the top of Y Bigl. Fig. 2. 'Post-Llanberis.'

ments both in grits and in the well-known conglomerate[1] are mainly:—

(1) Varieties of felsite which would find their counterparts in the 'Llyn Padarn' mass.
(2) Quartz-grains, often rounded, sometimes corroded.
(3) Felspar-crystals or grains, often twinned.
All these may well be derived from the quartz-felsite by the lake.
(4) Granitoid rock, and quartz and felspar, apparently from a rock of this nature.
(5) Quartzite which has a rather characteristic structure.[2]
(6) An altered-looking, often schistose mineral. It varies from pale yellowish to green, is slightly dichroic, and seems to give straight extinction. It bears some resemblance to an altered biotite, but cannot be certainly identified.

The altered mica-like mineral is especially found in two slides ('post-Llanberis'), but a small fragment of a similar variety occurs in one of the finer 'Cambrian' strata west of Llyn Padarn, and a similar mineral is seen in some of the quartz-felsite slides.[3] Also fragments of a spherulitic felsite occur in both sets, *e. g.* in a 'Cambrian' grit from east of Llyn Padarn, and in one called 'post-Llanberis' from west of the lake; and a similar character, associated with a perlitic structure, can be identified in a Moel

[1] S.—East of Llyn Padarn, synclinal by slate-railway. Figs. 1 and 2, *d.* 'Cambrian.'
T.—East of Llyn Padarn, by slate-railway. Figs. 1 and 2, *g*, *h*. 'Cambrian.'
U, V, W.—Three slides from east of Llyn Padarn. Figs. 1 and 2, *i*.
X, Y.—Two slides from west of Llyn Padarn, road by Tan-y-pant Cottages. Figs. 7 and 6, *a*. 'Post-Llanberis.'
Z.—West of Llyn Padarn, by road south of Tan-y-pant. Fig. 7. 'Post-Llanberis.'
α, *β*, *γ*.—Three slides from west of Llyn Padarn, hillside above Tan-y-pant. Fig. 7. 'Post-Llanberis.'
δ, *ε*.—Two slides from east of Llyn Padarn by slate-railway. Figs. 1 and 2, *a*. 'Post-Llanberis.'

[2] On examining a specimen from east of Llyn Padarn (from the hillside above the slate-railway) we find that it consists of subangular to partly rounded quartz-grains, which obviously have been slightly augmented by secondary quartz, though without losing their original outline. Between them, set as it were in the secondary quartz, are flakelets of a colourless mica. A few grains of felspar have also been present, most of them now replaced by the above-named mica and quartz, but two or three are unchanged (microcline, plagioclase, etc.). In the groundmass are several granules of yellow epidote, of pyrite?, hornblende?, and possibly rutile, with an opaque whitish decomposition-product, and two or three rather rounded zircons. The rock obviously was once a somewhat felspathic sandstone. It appears to have been converted into a quartzite before the pebble was made, and is rather more altered than is usual with a Palæozoic quartzite. This also, so far as one can judge from macroscopic observation, is true of the other pebbles.

[3] Even some granules of hæmatite appear to have their equivalents in one or two of the felstones. (Compare Sir A. Geikie, Quart. Journ. Geol. Soc. vol. xlvii. 1891, Pres. Addr. *Proc.* p. 99, and T. G. Bonney, Quart. Journ. Geol. Soc. vol. xxxv. 1879, p. 311.)

Tryfaen slide ('post-Llanberis'). The other classes of fragments make up the bulk of the rocks enumerated, both the 'Cambrian' so-called and the 'post-Llanberis.' Very much of the ground-mass apparently has been derived from the felstone, for in some cases it is by no means easily distinguished from a crushed variety of that rock.

To render the comparison more easy, we have separated the fragments of the acid from those of a basic type; but they may both occur in the same mass, as for instance, in the thinner bands of conglomerate or of grit at the synclinal by the railway on the western side of Llyn Padarn.

The results obtained from microscopic examination are thus clear and definite. Whether we compare rocks below the supposed unconformity with those above, on one side of the lake, or on the other, or on both—whether we compare the rocks of more basic or of more acid material, the coarser or (so far as they afford any evidence) the finer—the same kind of fragments can be recognized in both sets. Rocks of very different composition were being denuded before the supposed epoch of disturbance, and the same set of rocks was being worn down after that epoch. It would be a difficulty, as we have pointed out, if we had to suppose that the felsite was twice uncovered, but when we have in addition to believe that the same varieties of more basic rocks were in each case associated, so that identical conditions were reproduced before and after the great interval and interruption, this would be a coincidence suggesting the necessity for the strongest positive evidence of the unconformity. But at the crucial section, as we have shown, there is perfect gradation and continuity in the materials. Microscopically, as macroscopically, the unconformity does not exist.

Discussion.

Prof. Blake was glad that the Authors had attempted seriously to examine the question dealt with. Criticisms in such a spirit were in any case of value. The points dealt with in the abstract[1] read to the Society were covered by the remarks in his original paper, some of which he repeated.

Dr. Hicks said that he could not understand the position now taken up by Prof. Blake, as the evidence given in the paper clearly showed that the great felsite-ridge was at the base, and evidently older than any of the recognized Cambrian rocks. The Conglomerate resting on the ridge was sometimes diminished in thickness by faults and in other places represented by grits; but it contained everywhere material derived by denudation from the ridge, along with pebbles of other pre-Cambrian rocks. On the table were pieces of this Conglomerate which contained cleaved felstones, and large pebbles of a granitoid rock exactly like that forming the

[1] [This expression, unfortunately, is not quite accurate. I did not read an abstract, but gave an abridgment of the paper, sometimes reading, but mostly speaking from notes.—T. G. B., August, 1894.]

pre-Cambrian ridge at Caernarvon. The paper in his opinion gave the death-blow to the views put forward by Prof. Blake in regard to the succession of the older rocks in Caernarvonshire.

Mr. WHITAKER also spoke.

Prof. BONNEY replied that if Mr. Blake meant that another conglomerate was to be seen in the adit at Moel Tryfaen besides the one described by the Authors, it was in favour of their hypothesis of a fault. He could not admit that the felsite and purple slate were 'zigzagged together,' as Mr. Blake described. If the Authors had found the right place, the rock was not felsite but a felsitic grit. In the alleged unconformity by the slate-railway, the structure in the 'rain-spot breccia' was due to cleavage, not to bedding. Cleavage often disappeared in passing from finer to coarser strata—that was a matter of common experience. Moreover, cleavage could be just traced in the Conglomerate, and was perfectly developed in some interbanded fine grits or mudstones, a few steps uphill above the crag depicted. In answer to a question asked, he might remark that the Authors had carefully avoided the pre-Cambrian question, as foreign to the immediate issue of their paper, so he must decline to express his opinion on the subject.

39. *On the* Microscopical Structure *of the* Carboniferous Dolerites *and* Tuffs *of* Derbyshire. By H. H. Arnold-Bemrose, Esq., M.A., F.G.S. (Read June 6th, 1894.)

[Plates XXIV. & XXV.]

Contents.

I have, in the first place, to thank Mr. Teall for the suggestion that I should work out the Derbyshire Toadstone by the modern petrographical methods. I am not aware that the results of any detailed examination of the rocks have been published. Mr. S. Allport described five specimens from Matlock Bath and one from Bonsall.[1] I have examined his specimens and find them to be much more altered than the rock is in many places. The Cave Dale rock has been described and the Tideswell Dale rock has been both described and figured by Mr. Teall.[2]

The first person who wrote about the rock and called attention to its igneous nature was, I believe, Whitehurst, the clockmaker of Derby.[3] He considered it to be intrusive, but it is now generally admitted to be contemporaneous with the Carboniferous Limestone.

[1] 'On the Microscopic Structure and Composition of British Carboniferous Dolerites,' Quart. Journ. Geol. Sol. vol. xxx. (1874) pp. 529–567.

[2] 'British Petrography,' pp. 209, 210, and pl. ix.

[3] 'An Inquiry into the Original State and Formation of the Earth,' by John Whitehurst, 1778, pp. 149 *et seqq.*

The rock occupied the attention of many writers previous to the use of the microscope in petrography, and various opinions have been expressed and statements made about the number of beds and the non-occurrence of lead ore in it. It should be pointed out, that owing to the vague use of the word 'Toadstone' by miners, their statements as to the number of beds must be accepted with reserve. It is now impossible to verify such statements, because most of the mines are closed. The local name 'Toadstone' is derived either from the supposed resemblance of the amygdaloidal varieties to the back of a toad,[1] or the word is a corruption of the German 'Todtstein' (Deadstone) and so called because it was supposed that no lead ore was found in it.[2]

Though a mineral-vein is often cut off by the Toadstone, there are some undoubted cases in which the lead-ore has been worked in that rock. About two years ago I visited the Wakebridge Mine near Crich, and examined the rock in which the ore was being worked. It was a much decomposed olivine-dolerite.[3]

All the outcrops except two occur in the Mountain Limestone. Near Kniveton are two outcrops of igneous rock among the Yoredale Beds (nos. 57–58). According to the Survey memoir they cut across the shale and limestone, so that their boundaries are faults or the Toadstone here is intrusive. Sir A. Ramsay considered the latter view the safer.[4] The rocks in the neighbourhood are so contorted that it is difficult to say how far these views are correct. I have not been able yet to spend enough time at the locality to come to any opinion on the matter.

The spheroidal structure is well developed in many places, notably in Tideswell Dale, Priestcliffe Lane, New Bridge, and a rude columnar structure occurs in Cave Dale, near Castleton, and in Tideswell Dale.

Where exposures are seen which show its relation to the limestones above and below it, there is no doubt about the age of the Toadstone. The Geol. Surv. Memoir, p. 123, gives reasons for the belief that it is contemporaneous with the limestones. According to the memoir, the Toadstone is never seen to cut across beds of limestone, and although clay beds below it have been in some cases baked and caused to assume a columnar structure, as in Tideswell Dale,[5] those resting on the Toadstone show no trace of alteration. The abundance of the amygdaloids in the upper part of a sheet, the bedded ash near Ashover, and the bedded agglomerate at Hopton are cited as evidence of its being interstratified with the limestone.

[1] 'Essai sur l'Oryctographie du Derbyshire, par M. Ferber,' quoted by Faujas de St. Fond in 1799, 'Travels in England, Scotland, etc.,' vol. ii. pp. 284 *et seqq.*; also J. Farey, 'General View of the Agriculture and Minerals of Derbyshire,' vol. i. (1811) p. 277.

[2] Green, 'Physical Geology,' 1882, p. 554.

[3] 'Notes on Crich Hill,' Journ. Derbyshire Archæol. & Nat. Hist. Soc. vol. xvi. (1894) pp. 44–51.

[4] Mem. Geol. Surv. North Derbyshire, 1887, pp. 86–87.

[5] 'On an Altered Clay-bed and Section in Tideswell Dale,' by the Rev. J. M. Mello, Quart. Journ. Geol. Soc. vol. xxvi. (1870) p. 701; also E. Wilson, Geol. Mag. 1870, p. 520.

Observations in the field confirm the opinion expressed by the Geological Surveyors. As additional evidence, there are two cases in which we have a bed of tuff succeeded by a lava-flow, and of the remaining 61 outcrops 11 prove to be tuffs. Of course in such outcrops of the Toadstone as nos. 5 & 6, where the relative position with regard to the limestone has not been exactly determined, it is impossible to say whether the rock is intrusive or interbedded. I have discovered no proofs of intrusion anywhere.

The Toadstone is found in a district measuring about 25 miles from north to south and 20 miles from east to west. The Geological Surveyors have mapped 60 outcrops, some of which are parts of the same flow.

The following Table (p. 606) gives a list of these outcrops. I have applied to each a number, commencing from the north, and the names of the chief places near which it passes, both for the purpose of this paper and for future reference and identification.

In column IV. the words 'Upper' or 'Lower' (with a cross reference) mean that there is clear evidence that the two outcrops in question are so related to one another, but it does not follow that all the outcrops marked 'Upper' are necessarily on the same horizon.

The specific gravity has been determined by a Walker's balance made by How. Two specimens were also weighed with a chemical balance. They gave 2·86, 2·87 with Walker's balance, and 2·876, 2·890 with the chemical balance. The determinations were therefore ·016 and ·02 less by Walker's than by the chemical balance.

The eighth column gives some idea of the comparative freshness of the three principal minerals in the least altered specimen from each outcrop of lava: thus *f* denotes that the mineral is fresh or unaltered, and in the case of olivine that it is altered only along the cracks; *a* denotes that it has undergone a less or greater amount of alteration, in some cases being entirely replaced by a pseudomorph. In eleven out of forty-five outcrops fresh olivine is found, in twenty-six fresh augite, and in thirty fresh felspar, and in ten all the minerals are found in a fresh state.

There are undoubtedly two beds at least which are recognized by the Geological Survey, but whether they extend over the whole district is uncertain. Two may be seen exposed on Chelmorton Low, outcrops 26, 19; Matlock Bath, 39, 40 and 41, 41, 40; Ashford, 31, 30; Lathkill Dale, 37, 36; Miller's Dale, 20, 19; Tideswell Dale, 17, 9; Cressbrook Dale, 8 *a*, 8 *b*; on Weathery Low, 15, 14; and near Brook Bottom, 7 *a*, 7 *b*.

Outcrops 13, 14, 25, 26, 27, 28, now separated by denudation, were probably once connected and formed one bed, which would be the lower one of the district about Miller's Dale. Nos. 17, 20, 24 might have belonged to this bed. Outcrops 9, 15, 19, and perhaps 21 and 22 probably formed the upper bed of the district. Two beds also appear at Ashford and in Lathkill Dale. There seem to be, then, two well-marked beds or lava-flows near Miller's Dale

Table of Outcrops.

No. of Outcrop.	Sheet of Geol. Survey Map.	Places passed through or near.		No. of thin Sections examined.	Specific Gravity. Least.	Specific Gravity. Greatest.	Description of Rock.	Comparative Freshness. Olivine.	Comparative Freshness. Augite.	Comparative Freshness. Felspar.
1	81 N.E.	Castleton, between Peak Castle and the Winnats.	......	1	2·50		Tuff.			
				2	2·66	2·67	Included blocks.			
2	do.	Castleton—Cave Dale	......	15	2·66	2·80	Olivine-dolerite with rhombic pyroxene.	*a*	*f*	*f*
3	do.	The Holmes, from Eldon Hill across Cunning Dale to near White Rake Barn.	......	1	2·90		Olivine-dolerite.	*f*	*f*	*f*
4	do.	Peak Forest	......	8	2·73	2·85	Ophitic olivine-dolerite.	*f*	*f*	*f*
5	do.	High Peak Tavern	......	1	2·89		Olivine-dolerite.	*f*	*f*	*f*
6	do.	Pittle Mere (see no. 60)	......	1	2·87		Ophitic olivine-dolerite.	*f*	*f*	*f*
7 *a*	do.	Brook Bottom	Lower, see 7 *b*.	3	2·60	2·70	Tuff.			
				2	2·68	2·74	Included blocks.			
7 *b*	do.	Water Lane, near Brook Bottom .	Upper, see 7 *a*.	2	2·66	2·84	Ophitic olivine-dolerite.	*a*	*f*	*f*
8 *a*	81 N.E. 81 S.E.	Litton, Cressbrook Dale	Lower, see 8 *b*.	4	2·68	2·87	Olivine-dolerite.	*a*	*f*	*f*
8 *b*	do.	Tideswell Lane head, Litton, Cressbrook Dale.	Upper, see 8 *a*.	5	2·44	2·50	Tuff.			
				4	2·58	2·72	Included blocks.			
9	do.	Hamerton, across Litton Dale to Tideswell.	Upper, see 17.	2	2·55	2·57	Olivine-dolerite.	*a*	...	*f*
10	do.	Wheston Lane; from Potluck through Wheston to Wheston Lane.	......	3	2·70	2·76	Olivine-dolerite, sub-ophitic.	*a*	*f*	*f*
11	**81 N.E.**	**Kemp's Hill. [There is probably no outcrop.]**								
12	**do.**	**Dove Holes**	......	1	......		**Clay containing limestone pebbles.**			

13	81 N.E. 81 S.E.	Fairfield, Dove Holes on N., Ridge Lane, Waterswallows, and Ashwood Dale to Sherbrook.	......	10	2·46		2·95	Olivine-dolerite.	*f*	*f*	*f*
14	do.	Blackwell Lane, Chee Tor, Tunstead, Small Dale, Wormhill Low, Wormhill, Monk's Dale.	Lower, see 15.	7	2·28		2·80	Olivine-dolerite.	*a*	*f*	*f*
				5	2·87		2·95	Olivine-basalt.	*f*	*f*	*f*
15	do.	Weathery Low	Upper, see 14.	1		2·75		Dolerite.	...	*f*	*f*
16	do.	Monk's Dale, where Hargatewall Road crosses it.	......	2	2·63		2·66	Ashy limestone.			
17	do.	Tideswell Dale	Lower, see 9.	9	2·77		2·87	Olivine-dolerite.	*f*	*f*	*f*
18	do.	Ravensdale Cottage, in Cressbrook Dale.	......	2		2·48		Tuff.			
19	do.	Great Low, Maeston, Chelmorton, Five Wells, Taddington, Priestcliffe, Diamond Hill, Litton Tunnel to Cressbrook Dale.	Upper, see 26.	4	2·46		2·66	Ashy limestone.			
				1		2·40		Tuff.			
				5	2·25		2·60	Olivine-dolerite.	*a*	...	*a*
				8	2·36		2·86	Olivine-dolerite.	*f*	*f*	*f*
				3	2·91		2·93	Olivine-basalt.	*f*	*f*	*f*
20	do.	Miller's Dale, at bottom of valley.	Lower, see 19.	2		2·55		Olivine-dolerite.	*a*	...	*a*
21	do.	Crichley Wood......................	......	1		2·66		Olivine-dolerite.	*a*	...	*a*
22	do.	Knock Low	......	1		2·76		Olivine-dolerite.	*a*	*f*	*f*
23	do.	Wormhill	......	1		2·65		Olivine-dolerite.	*a*	...	*a*
24	do.	Sandy Dale	......	4	2·57		2·75	Olivine - dolerite with rhombic pyroxene.	*a*	*f*	*f*
25	do.	Calton	......	1		2·93		Olivine-dolerite.	*f*	*f*	*f*
26	do.	Brierlow, Horseshoe Dale, The Bures.	Lower, see 19.	1		2·72		Olivine-dolerite.	*a*	...	*a*
27	do.	Foxlow, Haston House, Hindlow.	......	1		2·79		Olivine-dolerite.	*a*	...	*a*
28	do.	Harper Hill	......	2		2·70		Olivine-dolerite.	*a*	...	*f*
29	do.	Staden Low	......	3	2·70		2·87	Olivine - dolerite with rhombic pyroxene.	*a*	...	*f*
30	do.	New Bridge, Finwood to Monsal Dale.	Upper, see 31.	6	2·53		2·77	Olivine-dolerite.	*a*	*f*	*f*
31	do.	Lees Bottom (near Ashford)	Lower, see 30.	3	2·61		2·68	Olivine-dolerite.	*a*	...	*a*

Table of Outcrops (*continued*).

No. of Outcrop.	Sheet of Geol. Survey Map.	Places passed through or near.		No. of thin Sections examined.	Specific Gravity. Least.	Specific Gravity. Greatest.	Description of Rock.	Comparative Freshness. Olivine.	Comparative Freshness. Augite.	Comparative Freshness. Felspar.
32	81 S.E.	Taddington Fields. [Not found.]								
33	do.	Bakewell, in Wye Valley	......	2	2·64	2·79	Olivine-dolerite, sub-ophitic.	a	f	f
34	do.	do. Cracknowl House.	......	2	......		Tuff.			
				2	2·48	2·49	Included blocks.			
35	do.	Ditch Cliff, near Upper Haddon. [Not found.]								
36	do.	Upper Haddon, in Lathkill Dale.	Upper, see 37.	2	2·71	2·79	Olivine-dolerite.	a	f	f
37	do.	do. do. do. do.	Lower, see 36.	1	2·62		Olivine-dolerite.	a	...	a
38	do.	Bradford Dale	......	1	2·76		Olivine-dolerite.	a	...	a
39	81 S.E. 82 S.W.	Bonsall Lane, Nealow Lane, Bonsall, Ember Lane.	Lower, see 40.	5	2·57	2·68	Tuff.			
				5	2·74	2·99	Olivine-dolerite.	a	f	f
				5	2·80	3·00	Ophitic olivine-dolerite.	f	f	f
40	82 S.W.	Salter's Lane, Heights of Abraham	Upper, see 39.	4	2·55	2·75	Olivine-dolerite.	a	f	f
41	do.	High Tor Tunnel	Lower, see 40.	2	2·75	2·77	Olivine-dolerite.	a	f	f
42	do.	Upperwood, Cumberland Cavern .	......	2	2·64	2·70	Olivine-dolerite.	a	...	a
43	81 S.E. 82 S.W.	Via Gellia, both sides of valley. See no. 61.	......	2	2·67	2·72	Olivine-dolerite.	a	a	f
44	81 S.E.	Ible	......	2	2·63	2·89	Ophitic olivine-dolerite.	a	f	f
45	do.	Ible Wood lead-mine	......	1	2·94		Ophitic olivine-dolerite.	f	f	f
46	do.	Grange Mill, Shothouse Spring ...	......	2	2·55	2·66	Ashy limestone.			
				5	2·28	2·64	Tuff.			
				3	2·45	2·78	Olivine-dolerite.			
47	**do.**	**Greenlow**	......	0		**Too much for thin**	**decomposed sections.**			

48	do.	Aldwark Grange	......	1		2·70		Olivine-dolerite.	a	...	a
49	do.	Sacheverel Barn	......	2	2·60		2·67	Olivine-dolerite.	a	...	a
50	do.	Aldwark	......	1		2·67		Olivine-dolerite.	a	...	f
51	do.	Minninglow; specimen taken from wall. [Outcrop not found.]	......	1		2·80		Olivine-dolerite.	a	...	f
52	71 N.W. 72 N.E.	Middleton, Hopton Stone Quarry, Moor Barn.	......	3	2·68		2·80	Olivine-dolerite.	a	f	f
53	72 N.E.	Hopton	......	5	2·59		2·61	Tuff.			
				3	2·56		2·68	Included blocks.			
54	do.	Kniveton, N., near Lee Hall	......	3	2·50		2·54	Tuff.			
55	do.	Tissington. [Not found.]									
56	do.	Kniveton, S., near Lee Wood......	......	3	2·40		2·46	Tuff.			
				5	2·48		2·72	Included blocks.			
57	do.	do. Flats House, left bank of stream.	......	1		......		Olivine-dolerite.	a	...	a
58	do.	do. do. do. right do. ...	......	2		2·58		Olivine-dolerite.	a	...	a
59	82 S.W.	Ashover	......	5	2·18		2·49	Tuff.			
				3	2·51		2·57	Dolerite blocks.			
60	81 N.E.	Potluck, not mapped by Survey. Probably continuous with Pittle Mere, outcrop no. 6.	......	4	2·58		2·72	Ophitic olivine-dolerite.	a	f	a
61	71 N.W.	Middleton, crossing the road from that place to Rider Point. [Not found.]									

TABLE OF MINE-HEAPS EXAMINED.

101	71 N.W.	Wakebridge Mine, Crich (*in situ*).	......	4	2·60		2·75	Olivine-dolerite.	a	...	a
102	do.	Glory Mine-heap, Crich	......	2	2·61		2·69	Olivine-dolerite.	a	a	f
103	81 S.E.	Elton Mine-heap, near Winster .	......	6	2·46		2·65	Olivine-dolerite.	a	...	a
104	do.	Wheel Rake Mine-heap, near Alport.	......	1		2·58		Olivine-dolerite.	a	...	a
105	81 N.E.	Black Hillock Shaft-heap, near Tideswell.	......	1		2·76		Olivine-dolerite.	a	f	f
				1		2·84		Ophitic olivine-dolerite.	a	f	f

and Buxton. There may be three beds or even four. It will be seen from the Table that the microscopic structure of the rock does not settle the question. The only way of ascertaining the real number will be by careful mapping over the whole district, and working out the fossils in the different horizons of the limestone.

I have been unable to find the following outcrops which are mapped by the Geological Survey: nos. 11, 32, 35, 51, 55, and 61. In every case except one, before giving up the attempt, I have mapped the toadstone-outcrops from the 1-inch to the 6-inch map and walked carefully over the ground.

Kemp's Hill, Outcrop 11, is mapped as forming a closed curve or ring round the hill which lies between Peak Forest and the station of that name. I have found no traces of toadstone either in the walls or in the soil. On the contrary, I found that several new quarries have been opened in the limestone where toadstone is mapped. The subsoil is of a reddish-brown colour similar to that covering the limestone in the Small Dale quarries near by, and is not a decomposed toadstone. There are a number of swallow-like holes in the limestone just outside the ring of supposed toadstone which are similar to those found in the toadstone between Dove Holes and Peak Forest Station. I can hardly think that the former can have misled the Geological Survey officers. All the evidence that I can find is against there being a bed of toadstone on Kemp's Hill.

Dove Holes, Outcrop 12.—This I have found, but there are doubts as to whether it is an igneous rock. See under Tuffs.

Taddington Field, Outcrop 32.—I have only paid one visit to this place since mapping the rock, and have been unable to find the outcrop where marked. In the Geological Survey memoir it is said that the outcrop is difficult to find.

Ditch Cliff, near Bakewell, Outcrop 35.—In a field to the E. of the road are some large blocks of dolomitized limestone which might be taken for toadstone, before they are broken into. Limestone is seen in several places on the hill, and in the soil by the roadside. There are two or three blocks of toadstone in a wall near, and one in the road-embankment amongst pieces of limestone and chert. These blocks may have been brought from the Lathkill Dale upper bed no. 36, a few fields away, or they may be from the drift which covers the surface in the neighbourhood of Bakewell, especially at the cemetery. I found a granite-boulder less than ½ mile from this supposed outcrop. I question whether there was ever any outcrop of toadstone here.

Minninglow, Outcrop 51.—Where the outcrop is mapped, the fields are ploughed or covered with grass. A few blocks of toadstone are found in the walls, but stronger evidence than this is necessary to prove the existence of a bed.

Tissington, near Ashbourne, Outcrop 55.—I have not visited this particular locality since I obtained the 6-inch maps. On two visits I have failed to find it. The ground is much covered with drift, and some pieces of toadstone in it might have been taken for indications of a bed.

Middleton, Outcrop 61.—On the road to Rider Point I have found no exposure, the ground being covered with grass.

North of Fairfield Common, near the old racecourse (outcrop 13), a small strip of toadstone is mapped by the Geological Survey. Every exposure shows limestone. A small quarry has lately been made for the mending of walls. The section exposed shows 1 foot of soil, 2 feet of clayey soil containing a few lumps of toadstone, and then limestone in almost horizontal beds.

I am aware that the above evidence, except that regarding outcrops 11 and 35, is of a negative kind, and that the fact of my being unable to find the outcrops does not prove that they never existed. It is possible that some of them may have been exposed at one time, and that the exposures are now hidden.

I have added to the list three outcrops not mapped by the Geological Survey.

Brook Bottom, Outcrop 7, is mapped by them as one bed. It is clearly two—a tuff and a lava separated by beds of limestone. See under Tuffs, no. 7 *a*.

Litton, near Tideswell, Outcrop 8.—A lava and a tuff separated by limestone. See under Tuffs, no. 8 *b*.

Potluck, Outcrop 60.—This is exposed in a field in front of the rifle-target, and is probably continuous with that at Pittlemere, no. 6. Both are ophitic olivine-dolerites.

In addition I have examined specimens from Wakebridge Mine and from the following mine-heaps:—Glory Mine, Crich; Elton, Wheel Rake, and Black Hillock: and have descended three mines, viz., Mill Close, Wheel Rake, and Wakebridge. Only in the last have I seen the toadstone in place. In the New Key Cavern at Matlock Bath I have seen blocks of toadstone which were not *in situ*. I have also examined several specimens of the rock from other places which were not *in situ*. My object has been to examine every occurrence of the rock in detail from as fresh specimens as possible.

For convenience, this paper is divided into two parts: The Lavas (none of the rock having yet been proved to be intrusive) and The Fragmental Rocks or Tuffs.

Part I.—The Lavas.

1. Olivine.

Olivine occurs mostly in the form of phenocrysts and groups or nests of crystals. The phenocrysts vary in size from 5 millim. in length, down to the smallest measured, $\cdot 06 \times \cdot 08$ mm. Of fifteen large ones measured, ten are over 2 mm. in length, four over 3 mm., and one over 4 mm. The outline is generally very well marked, giving the usual six-sided sections with acute angles between the domes. Sections parallel to (100) and (010) are found showing a positive and negative bisectrix, and others perpendicular or nearly perpendicular to an optic axis. The outline is often well preserved when the olivine is altered to oxide of iron or some other mineral,

so that when a hand-specimen of rock is much decomposed it is easy to find the olivine-pseudomorphs with a lens. Fresh olivine occurs in twenty-eight thin sections from eleven outcrops. In most of these the greater part is entirely unaltered, except for a slight discoloration in the cracks, most of which are rectilinear. The curved cracks which are present, in some cases combined with an alteration on the outside of the mineral, result in large granules of olivine without crystalline form. Some of the crystals are corroded and eaten into by the groundmass, and thus contain felspar-laths and augite in granules.

In some specimens the size of the crystals varies considerably. In one from a basalt near Chelmorton, outcrop 19, there are a number of small ones perfectly bounded, and embedded amongst the augite and felspar of the groundmass. One measures $\cdot 08 \times \cdot 06$ mm., and shows a bisectrix perpendicular to the section. The largest measure about $\cdot 55 \times \cdot 4$ mm.

The olivine often occurs in groups up to 5 mm. in diameter, consisting of two or three or even eight or nine individuals. A specimen from Tideswell Dale Quarry, outcrop 17, contains a group of eight individuals which fit closely together but extinguish in different positions. Two of them appear to form a twin, the angle between their directions of extinction being 70°. Such groups are common.

A specimen from a basalt near Blackwell, outcrop 14, shows an interpenetrating twin, the two individuals being clearly marked in polarized light. The acute angle of one is about 65°, and that of the other about 73°. Both sections show a bisectrix, though not very clearly. The greater axis of elasticity of the section is in both individuals at right angles to the long axis. The angle between the long axes of each is 55°.

In another case the angle between the directions of extinction of the two individuals is 57°. Several cases occur like the following. Two individuals almost rectangular in section, the dome faces absent, are divided by the trace of the plane of composition. The section of one individual is at right angles to an optic axis, and that of the other extinguishes at an angle of 15° with the dividing-line. In another case one extinguishes parallel to its length, and the other at 25° with the dividing-line.

The olivine is replaced by iron oxide, calcite, serpentine, chlorite, and a mica-like mineral. The iron oxide is generally opaque. In one slide it is transparent dull red, and appears the same in polarized as in ordinary light. It is not dichroic, and shows no axial figure in convergent light: it is thus distinguished from olivine coloured by iron. The calcite is sometimes clear and composed of large crystalline pieces, at others cloudy, and shows aggregate polarization. The only pseudomorphs after olivine which require any description are two which are found to a very large extent in several outcrops. For convenience, I have called them the Potluck and Peak Forest pseudomorphs.

2. Potluck Pseudomorphs after Olivine.

In an ophitic olivine-dolerite from Potluck, outcrop 60, the olivine is replaced by a lamellar greenish-yellow or reddish-brown dichroic mineral. The greatest absorption takes place when the traces of cleavage are parallel to the short axis of the polarizer. A pseudomorph which shows neither cleavage-cracks nor dichroism gives in convergent light coloured rings and a bisectrix at right angles to the section. The plane of the optic axes is at right angles to the length of the original olivine-crystal, the angle between the optic axes is very small, and the double refraction negative. As a rule a pseudomorph behaves as a crystallographic individual, and not as an aggregate. The traces of cleavage are generally parallel to the length of the crystal. In the case of two pseudomorphs, each consists of two or more portions of the mineral differently orientated. In one the outer portion is of a green colour without dichroism, giving an optic axis outside the field and coloured rings in convergent light. It contains two isolated kernels with cleavage parallel to the length of the crystal. The other (see Pl. XXIV. fig. 3) consists mainly of the yellow mineral with cleavage parallel to its length, and polarizes in colours of the 1st and 2nd orders. It contains two isolated kernels cut perpendicular to the acute bisectrix. No fresh olivine occurs in the slide, nor has any been found in this outcrop.

In a specimen of more weathered rock from the same locality the augite and felspars are partly altered. The pseudomorphs of olivine have good crystalline boundaries, and are often entirely enclosed in an ophitic plate of augite. They are similar to those described in the previous specimen. They are yellow when the traces of cleavage are at right angles to the short axis of the polarizer, and brown when these are parallel to it. One extinguishes at an angle of 37° with the length of the crystal, and shows coloured rings and a nearly straight axial arm.

In a hand-specimen of the same rock glistening faces of a bronze or reddish-bronze colour are seen, having the characteristic outline of olivine and attaining sometimes a length of 4 millim. Examined with a lens they are seen to possess cleavage, and, on the glistening faces, the straight and curved cracks usual in olivine. The cleavage is easy in one direction, and flakes are readily detached with a knife. They often break at right angles to the cleavage-planes along the cracks. When mounted, the thin flakes appear brown or brownish-yellow by transmitted light. In convergent light they show a biaxial figure with a small angle between the axes, and negative double refraction. They are sometimes almost uniaxial. When a fragment does not lie on the cleavage-plane it shows dichroism, the greatest absorption taking place when the short axis of the polarizer is parallel to the traces of cleavage.

Similar pseudomorphs are found in outcrop 42, near Upperwood on Masson Hill. The felspars are slightly turbid, and no fresh augite or olivine is present. A six-sided section is bounded

by the faces (010) (110). The angle (110) $\wedge$ (1$\bar{1}$0) is 130°. It is subtended by the traces of cleavage, which are therefore parallel to 100, the macropinacoid of the original olivine. In another section the cleavage-traces subtend the angle 135°. Yet another section gives an angle of 77° between the dome faces. This is the angle for olivine in sections parallel to the brachypinacoid (010). The cleavage-traces are parallel to the length of the crystal and therefore to the C axis. Combining these results, it follows that the planes of cleavage are parallel to the macropinacoid, as in the case of iddingsite described by Lawson. A pseudomorph is often composed of several minerals which are arranged in zones parallel to the outline of the crystal. We have an outer zone of the mica-like mineral, with an inner portion of calcite and oxide of iron; or an outer zone of iron oxide, followed by a thick one of the mica-like mineral, and this again by a thin zone of iron oxide and a nucleus of calcite. All traces of the original olivine-cracks are lost, but the pseudomorph sometimes contains wide cracks filled with calcite. In some cases the olivine is replaced by iron oxide, with or without an outer border of chlorite or serpentine—pale and slightly dichroic, the fibres being irregularly arranged.

A specimen from New Bridge, near Ashford, outcrop 30, contains pseudomorphs similar to those from Potluck, except that most of the original cracks in the olivine are filled with iron oxide. In a more highly altered specimen (see Pl. XXIV. fig. 4) the pseudomorphs are dark green for rays vibrating parallel to the short axis of the polarizer, and light green or faint yellow for rays vibrating at right angles. The double refraction is strong, and the polarization-colours are similar to those of biotite. The cracks are filled with iron oxide, which has in some cases replaced more or less of the olivine nucleus. Cleavage-flakes taken from a hand-specimen behave much as those from Potluck. In several sections the cleavage-cracks subtend angles varying from 134° to 126° (110 $\wedge$ 1$\bar{1}$0), so that the traces of cleavage are parallel or nearly parallel to the macropinacoid. The whole pseudomorph has not always the same optical orientation throughout. In a section which gives an acute angle of 71° between the traces of the dome faces, the greater portion gives an acute bisectrix perpendicular to the section, and the plane of the optic axis is parallel to the trace of one of the dome faces. It contains three patches with dichroism and cleavage parallel to the length of the crystal.

3. Peak Forest Pseudomorphs after Olivine.

In Dam Dale, close to the village of Peak Forest, there is a good outcrop (no. 4) of ophitic olivine-dolerite. Seven thin sections have been examined. In the most weathered ones the augite is little altered, but the felspars are turbid. Pseudomorphs of olivine similar to those at Potluck are found. Instead of behaving as a crystallographic individual, the replacement-product sometimes consists of fibres irregularly arranged, in other cases part of the

pseudomorph consists of these fibres, and part of the lamellar mineral. Cleavage-flakes behave like those from Potluck.

There is also a second kind of pseudomorph which is found only in the less altered rock. Several of the larger olivines are entirely replaced by a pale yellow mineral, with traces of cleavage which are parallel to the long axis of the crystal, but which do not always run through its whole length. The cracks are filled with and bordered by a clear yellow substance (*a*), and this in turn is bordered by a pale yellow one (*b*). Both are bounded by lines parallel to the crack, except where two cracks meet, when *b* fills up the triangular space between them; or where two parallel cracks are near together, when *b* fills the space between them. Both are dichroic, *a* becoming a darker yellow when the short axis of the polarizer is parallel to the length of the crystal, and *b* being yellow when the short axis of the polarizer is perpendicular to the length of the crystal, and a 'solid'-looking bluish-green when it is parallel. Both *a* and *b* extinguish together over the whole crystal, parallel to the long axis of the section. In some pseudomorphs the mineral is non-dichroic, and extinguishes at an angle of 40° or 46° with the length of the olivine-crystal.

An olivine-crystal, more than half of which is unaltered, has the plane of the optic axes at right angles to its length. The cracks are bordered by *a*, which is non-dichroic and yellow, and *a* in turn is bordered by *b* with slight dichroism. Both these substances become extinct parallel to the length of the crystal, no matter in what direction the cracks run. The green substance (*b*) is followed by an irregular zone of partly altered olivine, which sends out shoots or fangs into the fresh olivine-nuclei. Sometimes the green substance is non-dichroic, and has no traces of cleavage. Examined under convergent light, with a $\frac{1}{12}$-inch immersion-lens, both *a* and *b* show in such cases the emergence of a negative bisectrix, the angle between the optic axes being very small.

Cleavage-flakes taken from the outer and inner portions of a hand-specimen were examined. When non-dichroic, they give in convergent light an almost uniaxial figure with coloured rings having negative double refraction, the acute bisectrix being perpendicular to the plane of cleavage. In some fragments both the yellow and green kinds are seen, showing that they do not easily become detached one from the other. The cleavage is seldom very perfect, and the fracture is often fibrous.

The cleavage (when it occurs) is often parallel to the macropinacoid of the olivine, as in the case of the first kind of pseudomorph or that found at Potluck and other places above described. Olivine-nuclei showing the emergence of a positive bisectrix at right angles to the section, and therefore cut parallel to the macropinacoid, polarize in green and greenish-yellow of the first order. In such cases the pseudomorphous parts are not dichroic, and show no traces of cleavage. Nuclei cut parallel to the negative bisectrix and therefore parallel to the brachypinacoid, polarize in yellow and blue of the first order. The pseudomorphous part is dichroic, and polarizes in

blue and green of the first order and green of the second: the slight traces of cleavage, and the fibres, where present, are parallel to the length of the crystal. It follows that the pseudomorphs possess slight cleavage in planes parallel to the macropinacoid of the olivine.

The Potluck and Peak Forest varieties of pseudomorph are also found in outcrop 39, Nealow Lane, near Matlock. Both the ophitic and granular augite occur. The felspars and augite are generally fresh. I have collected specimens of rock of both kinds of structure which can be arranged in two series, each being similar to those of the Peak Forest rock above described. The most altered in each series give cleavage-flakes like those from Potluck, the olivine being replaced by the mica-like mineral, and the least altered contain nuclei of fresh olivine surrounded by the Peak Forest variety of pseudomorph. In one thin section of the ophitic rock serpentine also occurs in the olivine-cracks. In the same section we have the Peak Forest pseudomorph. In the freshest specimen there is none of the dichroic mineral, and the olivine is altered to serpentine along the cracks. The question we have to discuss is whether the Potluck pseudomorph is a replacement of olivine by biotite or some mineral similar to it, or by the mineral called iddingsite, or by some other mineral.

Prof. A. Renard [1] describes the replacement of olivine by mica in the rocks of Platform Island. The pseudomorphs have the colours, absorption, and extinction of biotite, and sections parallel to the cleavage exhibit a black cross with negative double refraction. The replacement of olivine by leaves of biotite is described by J. J. Sederholm.[2] M. Schuster [3] describes the partial replacement of olivine by biotite in an anorthite-gabbro from Birchville, California. H. von Foullon [4] describes the replacement of olivine by biotite in a melaphyre. The only proofs he adduces are its colour, dichroism, and parallel fibres. Nuclei of olivine often remain unaltered.

Rosenbusch [5] describes pseudomorphs of olivine with leaves parallel to (010) very pleochroic, the greatest absorption being parallel to the leaves. The colour is between iron glance and pseudo-brookite. He says that it has not been proved whether it is a red colouring of olivine with clearer laminations parallel to (010) or a new substance. Dana [6] states that olivine sometimes becomes brownish or reddish-brown and iridescent. It also splits into thin laminæ as the change goes on, sometimes so as to resemble a mica. Prof. Iddings describes the alteration of olivine [7] to a fibrous material

[1] Report of 'Challenger' Expedition, vol. ii. (1889) pt. vii., Petrology of Oceanic Islands.

[2] 'Studien über archäische Eruptivgesteine aus dem südwestlichen Finnland,' Tscherm. Min. u. Petr. Mitth. vol. xii. (1891) p. 106.

[3] Neues Jahrb. Beilage Band v. (1887) p. 520.

[4] 'Ueber Eruptivgesteine von Recoaro,' Tscherm. Min. u. Petr. Mitth. vol. ii. (1880) p. 481.

[5] 'Mikroskopische Physiographie,' vol. ii. (1887) p. 489.

[6] 'System of Mineralogy,' 1875, p. 258.

[7] 'Geology of the Eureka District,' U.S. Geol. Surv. Mon. vol. xx. (1892) pp. 388–390.

which runs in parallel lines throughout the crystal. The fibres have a light-yellow colour at first, which deepens into a reddish-brown or blood-red as the decomposition proceeds; they polarize brilliantly and show sometimes a faint pleochroism. Sections parallel to the cleavage-planes give in convergent light a nearly uniaxial interference-figure, and the plane of the optic axes is perpendicular to the direction of the fibres. According to his illustration, the fibres appear to run at right angles to the length of the olivine-crystal. Part of the olivine is often unaltered. In one case he thinks that this mica-like mineral is probably a foliated crystalline form of serpentine, namely, thermophyllite.

Lawson[1] describes a similar mineral which he does not consider to be an alteration-product of olivine (no fresh olivine is found in his rocks) and to which he gives the name of 'iddingsite.' It has the same crystalline form as olivine, and the planes of cleavage correspond to the macropinacoid of that mineral. Cleavage-plates are biaxial, the plane of the optic axes is parallel to the **C** axis of the olivine and perpendicular to the cleavage-planes. The interference-colours are almost like those of muscovite. In thin sections the mineral ranges from a deep chestnut-brown to a citron-yellow or clear yellowish-green. As in the case of the mineral described by Iddings, fragments heated in hydrochloric acid soon lose their colour, the iron being extracted, but their optical properties remain unaltered. As a result of qualitative chemical tests Lawson describes iddingsite as a hydrated non-aluminous silicate of iron, lime, magnesia, and soda.

Mr. Teall showed me a thin section containing iddingsite. This mineral had outlines similar to those of olivine, but appeared almost opaque in thin sections, and more like hæmatite. The Derbyshire mineral is always very transparent.

Mr. Allport[2] describes a dolerite from Duncarnock in which the olivine is "partly converted into hæmatite," the exterior being of a light red colour, often iridescent, and splitting into thin laminæ. I have examined his specimens now in the Natural History Museum, South Kensington. In several thin sections are pseudomorphs consisting of a fibrous or lamellar dichroic mineral something like the Upperwood pseudomorphs. In a few cases they show rings, and the arms of a cross in convergent light. (See thin sections, nos. 1523, 1524, 1526, Nat. Hist. Museum.)

The Potluck pseudomorph is biaxial, with a very small axial angle, has negative double refraction, and often the colour and strong double refraction of biotite in thin sections. As in the case of iddingsite, it behaves generally as a crystallographic individual, and not as an aggregate. The cleavage-planes are also, in every case where I have been able to apply any test, in thin sections, parallel to the macropinacoid of the original olivine.

[1] 'The Geology of Carmelo Bay,' University of California, Bulletin of the Department of Geology, May 1893, Lawson and Posada.

[2] 'On the Microscopic Structure and Composition of British Carboniferous Dolerites,' Quart. Journ. Geol. Soc. vol. xxx. (1874) p. 541.

It differs from iddingsite in having the plane of the optic axes generally perpendicular to the *c* axis (001) instead of the *b* axis (010) of the olivine. In one case it is perpendicular to the *b* axis and in another parallel to a dome face. Another difference is that sometimes various parts of a pseudomorph, though behaving as crystallographic individuals, have a different optical orientation. These variations, and the occurrence of fresh olivine in two of the same outcrops, though not in the same specimens as this pseudomorph, point to the latter as being a replacement of the olivine, and not an original separation from the magma. This view is confirmed by the occurrence of fresh olivine-kernels with the cracks altered to serpentine, and the olivine also partly replaced by the Peak Forest kind of pseudomorph in the Pittle Mere outcrop, which was probably continuous with the Potluck outcrop.

Cleavage-flakes from the most altered specimens of the Potluck rock were detached by the knife, and separated from fragments of other minerals under a low power. They are not elastic like mica, but are brittle, often, though not always, breaking along the cracks of the original olivine. Treated with dilute hydrochloric acid on a glass slide and warmed, they soon change from red to yellow and become colourless. They lose their dichroism, but flakes lying on the cleavage-plane still show an almost uniaxial figure. If the action be continued a little longer, they become isotropic. When heated in the closed tube, a little water is given off.

Mr. L. Archbutt, F.C.S., F.I.C., kindly tested some of the flakes for me and obtained the following results:—

"The quantity of mineral received for analysis weighed about 11½ milligrammes. Six and a half milligrammes were finely powdered, and digested with a little pure hydrofluoric acid and a small drop of sulphuric acid in a platinum crucible, at a gentle heat for some time, and then evaporated to dryness and heated to faint redness. The residue was dissolved in hydrochloric acid, which gave a clear solution; this was diluted with a strong solution of hydrogen sulphide, and a *trace* of brownish precipitate mixed with sulphur was filtered off. The sulphuretted hydrogen was expelled by evaporation, the iron oxidized by a few drops of bromine water, and the excess of bromine evaporated off. A slight excess of ammonia was then added, which produced a red precipitate: this was tested for alumina. It was dissolved in hydrochloric acid and boiled with pure potash in excess, which threw down a comparatively large precipitate having the colour of pure ferric hydroxide, which was not further examined; the filtrate was evaporated with excess of pure solid ammonium chloride, and a comparatively fair-sized precipitate of alumina was thus obtained, which was not further examined. As potash purified by alcohol always contains traces of alumina, the precaution was taken of testing rather more of the potash than was used in the analysis, in the same way, but the amount of alumina obtained was insignificant. The filtrate from the ammonia precipitate was mixed with a few drops of a strong solution of hydrogen sulphide, but no precipitate of manganese

or zinc sulphide was obtained. A few drops of ammonium carbonate were then added, which produced no precipitate, neither did ammonium oxalate, after waiting long enough for any precipitate to appear; the absence of lime was therefore inferred. On adding ammonium phosphate, a small precipitate of ammonium-magnesium phosphate was obtained, which was filtered off, and after removing phosphoric acid from the filtrate by lead, and the excess of lead by sulphuretted hydrogen, and then evaporating to dryness and heating to expel ammonium salts, the residue gave a decided reaction for potassium when tested by platinum chloride, and a very decided reaction for sodium by the flame-test. Another 5 milligrammes of the mineral were rubbed to a powder with 10 milligrammes of fluorspar free from silica, and gently warmed in a very small platinum crucible. A drop of water in a loop of platinum wire was supported within the crucible a little above the surface of the fluid mixture, and an unmistakable precipitate of silica was formed in the drop. The whole analysis was carried out in platinum, and on account of the minute quantity submitted to examination, every care was taken to use pure reagents and those in the minimum proportion necessary. The oxides found, besides silica, were iron oxide in comparatively large quantity, a fair amount of alumina, a small quantity of magnesia, and small quantities of soda and potash. The estimates of relative *proportion* can of course only be regarded as rough guesses."

These results differentiate it from iddingsite, which, according to Lawson, is non-aluminous, and contains lime, whilst the Potluck mineral contains potash and alumina, but no lime. The qualitative analysis points rather to a biotite: the optical properties also agree with those of an almost uniaxial mica. Only its brittleness and want of elasticity make it differ physically from biotite, though Rosenbusch [1] says that the elasticity of cleavage-flakes becomes less, even to brittleness, in phlogopites and biotites, and is often quickly lost when biotite begins to alter to chloritic aggregates. The optical axial angle is too small, and the pleochroism is too great, for bastite or for antigorite.

Sprödglimmer and chlorite are the only minerals which have a like development of cleavage in kind and degree.[2] Of the former group xanthophyllite and clintonite, which have negative double refraction, have only moderate pleochroism and are hardly attacked by acids. The double refraction of chlorite is too feeble.

The Peak Forest pseudomorph, though differing in appearance from the Potluck one, has the same optical properties. The only difference is in the colour and small degree of cleavage. It undoubtedly replaces olivine. The colour is green and yellow in the same crystal, while that from Potluck is generally red or green or yellow throughout. In two outcrops we have the two kinds of pseudomorphs, though not together in the same thin section. I am inclined to think that the Peak Forest pseudomorph is a transition-stage towards the formation of the Potluck pseudomorph. We

[1] Mikr. Physiogr. vol. i. (1885) p. 476.
[2] *Ibid.*

should thus have the change proceeding from the cracks of the original olivine, in a direction parallel to the length of the crystal, and not normal to the cracks, as in the case of the alteration to serpentine. The whole olivine-crystal is at length replaced by this mineral, which is yellow along the cracks and green in the remaining parts. More perfect cleavage is developed, the iron becomes oxidized, colouring the mineral red instead of green and yellow, and we have the mica-like mineral as a resulting product, the cleavage-planes being parallel to the macropinacoid and the plane of the optic axes often perpendicular to (001).

The mineral described by Prof. Iddings is evidently a pseudomorph of olivine. Lawson considers that iddingsite is not a pseudomorph of olivine, that it is separated from olivine by its chemical, optical, and physical characters, and states that no trace of olivine or its ordinary decomposition-products has been detected in his thin sections. In the case of the Derbyshire mineral the same remarks would hold good, if we only had specimens from Potluck and Upperwood to deal with (even in these outcrops, if the rock were quarried, fresh olivine might be found in less altered portions). But we have the same mineral associated with olivine in two other outcrops. It may be possible, therefore, that iddingsite is a pseudomorph or replacement of olivine, but that the replacement has extended throughout the whole of the rocks in question.

In the absence of a quantitative analysis of the Potluck pseudomorph, we cannot be certain whether it is a mica. So far as the present evidence goes, it would appear to be a mineral allied to biotite or to clintonite, and may be the same as that which Prof. Renard considered from its optical properties to be biotite. At present I prefer to call it a 'mica-like mineral replacing olivine.'

4. Rhombic Pyroxene.

This mineral resembles that in the lava of Eycott Hill described by Prof. Bonney as altered enstatite.[1]

Mr. Teall kindly lent me several thin sections of the Eycott Hill rock for comparison. The pyroxene in the Derbyshire rock is pale green or yellow in transmitted light; longitudinal sections are more or less pleochroic, the absorption being greatest when the traces of cleavage and the length of the section are parallel to the short axis of the polarizer. Extinction always takes place parallel to the length of the section.

The mineral occurs mainly in three localities. A specimen from *Staden Low*, outcrop 29, contains both individual crystals and groups of crystals. The largest crystal measures 1×4 millim. It has traces of cleavage parallel to its length, behaves as above stated, and gives pale yellow polarization-colours between crossed nicols. One individual of a group of about 12 gives an eight-sided section. The angles between 3 consecutive pairs of adjacent sides are 134°,

[1] Geol. Mag. 1885, pp. 76–80.

130°, and 130°. In convergent light an optic axis is often seen to be outside the field of view. Other specimens from the same outcrop do not contain this mineral; it is probably altered to calcite. The rock also contains pseudomorphs of olivine, two generations of felspar little altered, magnetite or ilmenite, some interstitial matter, various alteration-products, but no traces of a monoclinic pyroxene.

Sandy Dale, Outcrop 24.—Some sections of pyroxene in a large group are yellow, and others pale green by transmitted light. The former polarize in a bright yellow, and the latter in a dark grey tint. The former are dichroic, giving two shades of yellow, and the latter two of green. The former show in a convergent light the arm of a biaxial figure and sometimes coloured rings, the latter are nearly perpendicular to an optic axis. This mineral often occurs in groups of two or more individuals: three slides out of the four contain it. In the Sandy Dale rock are pseudomorphs of olivine, but there is no augite, and it differs from the Staden Low rock in not always having two generations of felspar. On the whole, the rhombic pyroxene is found more often in groups than in the specimens of the Eyecott Hill rock which I examined. It possesses not only a better crystalline outline, but behaves more often as a crystal, and unlike an aggregate pseudomorph, the whole extinguishing together. The cleavage is not so well marked, and the fibrous and confused structures are present in a less degree, and only in the more altered specimens.

A small portion of the Sandy Dale rock was pounded and passed through a sieve of 80, but was stopped by one of 120 meshes to the inch. A number of fragments of a slightly dichroic green mineral were thus obtained. One only gave a negative bisectrix, with a small angle between the optic axes. This is probably bastite.

The rhombic pyroxene also occurs in some specimens of the Cave Dale rock, outcrop 2, whilst in others there is comparatively fresh augite in grains. Small traces of it are also found in outcrops 23, 27, 28, 31, 37, and 48, and in 14 at the entrance to Chee Tor Tunnel.

We have, therefore, in these rocks a rhombic pyroxene with cleavage poorly developed, which in some cases is altered to bastite.

5. Augite.

This occurs in large ophitic plates, large and small phenocrysts, small irregular grains, and in prisms which give lath-shaped sections.

The ophitic plates vary in size from 7·5 mm. in length and from 5 mm. × 2·5 mm. downwards. The large plates enclose many felspars and also olivine-crystals, which are more or less altered along the cracks, though the augite appears quite fresh. This structure runs throughout the slide, so that the whole of the augite has crystallized last and formed the groundmass. Although these plates have no crystalline boundary, cleavage-cracks are often well developed in them. In some sections the sets of cracks are nearly at right

angles one to another, and the direction of extinction bisects the angles between them. These are nearly perpendicular to the **C** axis. Others have fine parallel cracks which often run in the direction of the length of the plates. They appear in the different portions into which a plate is divided by the felspars. If they represent the usual prismatic cleavages, we have sections out of the prism zone. The augite often extinguishes at large angles with these cracks. After measuring a number of angles of extinction, I find that the largest which the axis of least elasticity of the section makes with the cleavage-cracks are 40°, 42°, 45°, and 52°. The angle $c \wedge y$ is therefore 52° or more. Amongst the ophitic plates are many twins. In some cases, both individuals possess cleavage-cracks parallel to the trace of the plane of composition, and extinguish symmetrically with regard to it. These sections are out of the prism zone, and the plane of composition is (010). I have measured the angles which the direction of extinction of each individual makes with the twinning-line, and the greatest I have found is 45°. In these plates the angle $c \wedge y$ is 45° or more.

Some small plates of augite enclose one or two felspars, or have the end of a felspar sticking into them. They sometimes occur with the ordinary granular augite, and are distinct from the true ophitic structure.

The phenocrysts are of the usual form, and the sections are often bounded by six or eight sides. The largest measured is 1·65 × 1·20 mm. Some of the biggest crystals are corroded, and others contain portions of the groundmass. The hour-glass and the zonal structures are very frequent. The outer portion of an individual of a twin crystal often extinguishes differently from the inner portion. As in the case of olivine, there are many groups the individuals of which can only be distinguished in polarized light. The smaller phenocrysts are similar to the larger ones, and their boundaries quite as well defined.

The lath-shaped sections have a well-defined outline, and sometimes cleavage-cracks parallel to their length. They often extinguish when the cross-wire is inclined at an angle of about 45° with their length. They are distinguished from untwinned felspars by their polarization-colours. I have measured a number of angles made by the least axis of elasticity with the long axis of the prism, and the following are the greatest: 41°, 42°, 43°, 45°, 45°, 45°, and 46°. Some of them are twinned. The grains vary in size, and are irregular in shape. The phenocrysts, lath-shaped sections, and grains, or the two former only, occur sometimes together in the same thin section, so that we have two generations of augite. Lath-shaped sections and grains occur together, but most often the grains occur alone.

6. Felspar.

The felspar, which is triclinic, occurs in two generations. Of the fifty-nine largest crystals measured, one is over 3 mm. in length, ten are over 2 mm., seventeen are over 1 mm., twenty are over 5,

nine under 5 mm. Some of these are broken and corroded, and some have zonal structure. They belong to the first generation, and give lath-shaped or tabular sections. The majority of the smaller felspars give lath-shaped sections. They are often twinned on the albite plan. I have measured a large number of extinction-angles of adjacent lamellæ, and have obtained about fifty in which the extinctions take place symmetrically with reference to the trace of the plane separating the lamellæ. These sections are out of the zone perpendicular to the brachypinacoid (010). The felspars occurring in the ophitic augite collected from seven localities give the following angles of extinction for adjacent lamellæ :—

$$\begin{array}{c}
10^\circ . 10^\circ . 13^\circ . 13^\circ . 20^\circ . 20^\circ . 25^\circ . 27^\circ . 25^\circ . 27^\circ . 28^\circ . 27^\circ . 30^\circ . 32^\circ \\
\hline
10^\circ . 11^\circ . 13^\circ . 17^\circ . 20^\circ . 22^\circ . 25^\circ . 28^\circ . 30^\circ . 29^\circ . 30^\circ . 33^\circ . 35^\circ . 37^\circ
\end{array}$$

All, except the first four, may be referred to labradorite or perhaps to anorthite, and the two last to a plagioclase intermediate between labradorite and anorthite. According to this test, therefore, the majority of the felspars in the ophitic olivine-dolerites of Derbyshire may be labradorite; this agrees with the determinations of Schilling for similar rocks of the Harz, though in the Derbyshire rocks some of the felspars are probably bytownite. In a lath-shaped section one individual extinguishes at an angle of 32°, and the other has zonal structure, the outer portion extinguishing at an angle of 35°, the inner at an angle of 45°, and the intermediate portions at angles between 35° and 45°. This may be referred to anorthite.

In the rocks with granular augite, from 16 slides I have obtained 26 cases of symmetrical extinction. In 22 of them the extinction-angle between two adjacent lamellæ varies from 42° up to 61°. The maximum for labradorite is 62° 30′. Three others give angles of 63°, 68°, and 70°, and may be referred to bytownite or anorthite; and one gives an angle of 75° or extinctions referred to the trace of (010) the angles 35° and 37°, and may be referred to anorthite. Several cleavage-flakes from a specimen near Tideswell Dale Quarry (outcrop 17) in convergent light show an optic axis just outside the field of view. They may be referred to bytownite. These results confirm the view expressed by Teall[1] that the prevailing felspars in the basic division of the normal plagioclase-rocks belong to the labradorite-anorthite group.

7. Structure of the Lavas.

There are only eleven thin sections from eight outcrops which contain no certain traces of olivine. These are from specimens of rock which has suffered a certain amount of decomposition. In fresher specimens from the same outcrops, olivine or its pseudomorphs are found. In only one of them, namely, outcrop 15, have I seen no traces of olivine. The rock is much weathered, and I have little doubt that a less altered specimen would be found to contain olivine-

[1] 'British Petrography,' 1888, p. 147.

pseudomorphs. Plagioclase occurs in every thin section examined. Augite has been found in all the sections, except No. 30. In some of them is the rhombic pyroxene, and in others are secondary calcite, serpentine, and chloritic aggregates which probably have replaced the augite. Magnetite or ilmenite occurs in nearly all the sections. The rock consists essentially of olivine, augite, plagioclase, and magnetite or ilmenite.

There are three main types of structure, olivine-dolerite, ophitic olivine-dolerite, and olivine-basalt.

The olivine-dolerite occurs most frequently. It consists of augite in grains, olivine in idiomorphic crystals, plagioclase giving lath-shaped and tabular sections, and magnetite or ilmenite in rods and grains. The Tideswell Dale Rock figured in Teall's 'British Petrography,' pl. ix. fig. 2, well illustrates this type, except that the olivine is in many cases much less altered than in the figure. In the least-altered specimens there is, as a rule, not a large amount of interstitial matter. In outcrops 9, 56, 57 the groundmass sometimes consists of a small felt of felspar-laths often giving parallel extinction, and similar to the microfelsitic base of the Tynemouth dolerite figured by Teall.[1]

The ophitic olivine-dolerite consists of augite in ophitic plates forming the groundmass, in which are embedded the idiomorphic olivine, the plagioclase often giving large lath-shaped sections, and magnetite or ilmenite. Pl. x. in Teall's 'British Petrography' illustrates this structure. The minerals in the least-altered specimens of the Derbyshire rock are quite as well preserved as those in the Scottish Tertiary dolerites. This structure occurs only in outcrops 4, 6, 7 *b*, 39, 44, 45, 60, and Black Hillock 105. In only one of these, namely 39, have I found the granular augite, and in no specimen both the ophitic and granular augite together—if we except a few cases in which some granules of augite are penetrated by one or more felspars. When the ophitic augite occurs, it generally forms the whole groundmass in all specimens which have been collected from the outcrop.

The olivine-basalt contains olivine and large augite-phenocrysts. (In outcrop 14 the augite is often larger than the olivine, and sometimes encloses a small crystal of it.) The phenocrysts of olivine and augite lie in a groundmass of small felspar-laths, of augite in small phenocrysts, grains, and prisms which give lath-shaped sections, and of magnetite or ilmenite. There is little interstitial matter present. The rock is in a very good state of preservation, all the minerals being quite fresh, except that the olivine is sometimes slightly altered along the cracks. The rock is a typical olivine-basalt. A thin section containing augite-prisms and magnetite is similar to one of the Dudley basalt figured in 'British Petrography,' pl. xxiv. fig. 2, except that the Derbyshire rock contains olivine. I have found this basalt only in outcrops 14 and 19, and in each case its specific gravity is greater than that of the olivine-dolerite

[1] 'British Petrography,' 1888, pl. xii.

with granular augite which makes up the remainder of the outcrops (except the tuff underlying No. 19).

In some places and outcrops the rock is so much altered that it might be called an olivine-diabase, or diabase-mandelstein. Even in the same outcrop it may be a dolerite little altered in one place and an olivine-diabase in another, while a further stage of decomposition results in a more or less granular, clayey material containing spheroids of diabase. I have described it as an olivine-dolerite in the Table (p. 608).

Part II.—The Fragmental Rocks or Tuffs.

The tuffs cover a much more extensive area than had been previously supposed. Two outcrops, namely, those at Ashover and at Hopton, are mentioned in the Geological Survey memoir. In addition to these I have found eleven others. I am not aware that any of them have been microscopically described, and for this reason and because in most cases they have undergone so little alteration a detailed description of them is here given. Speaking generally, petrographers have not bestowed so much consideration on the fragmental igneous rocks as they have on the massive ones. In the field, it is sometimes difficult to distinguish a tuff from a decomposed amygdaloidal dolerite. A method that I have found very useful is to carry a small file for filing the edge of the specimen. After it is thus prepared and wetted, it is easy with the aid of a lens to make out the lapilli in a fragmental rock.

The tuffs occur in all parts of the district, north, south, east, west, and centre, and may be divided into a northern group and a southern group, like the lavas. The northern group includes outcrops 1, 7 *a*, 8 *b*, 16, 18, 19, 34, and the southern outcrops 39, 46, 53, 54, 56, 58. In 19 and 39 the layers of tuff are succeeded immediately by a lava-flow. In 7 *a* and 8 *b* we have a lava-flow and tuff-beds separated by bands of limestone. In 7 *b* the lava is uppermost, while in 8 *b* it is the lower bed.

Castleton, Outcrop 1.—This is seen in a field behind Goose Hill Hall, towards Speedwell Cavern. It is triangular in shape, and forms a ridge about 80 feet in length. The outcrop is almost entirely covered with grass. The rock is of two kinds, one soft and loose in texture, made up of fragments: a tuff; the other, probably blocks in this tuff, of a light-grey colour, hard, and weathering very much like limestone. With the aid of a lens, small felspar-crystals may be seen.

Two specimens of the compact rock were examined (sp. gr. 2·67 and 2·66). Large calcite-pseudomorphs after olivine occur. They often contain portions of the base with small magnetite-grains, and in one case two felspar-laths. The felspar occurs in a few rhombic sections, also in large and small lath-shaped sections, often ragged or forked at the ends, and in skeleton-crystals. The laths generally have parallel extinction, and the mineral is partly or wholly altered

to calcite. The base is isotropic, and in polarized light structureless. In ordinary light it is seen to be of a brown colour, with a felt of crystallites. The crystallites are often curved, feather-like in arrangement, and frequently sprout from the ends of a felspar-lath, so that they may perhaps be referred to felspar.

A specimen of the fragmental rock (sp. gr. 2·50) consists of lapilli, some of which have a white porcellaneous appearance. Under the microscope are seen several lapilli of a rock similar to that last described. Some small ones are a dense black, with a thin, light yellow border; sometimes they contain a few felspar-laths. The larger ones, which are black or dark brown, are cracked, the cracks being filled with a light yellow material or with calcite. In reflected light the brown portions look like a cream-coloured porcelain, parts of which are dirty and tinged with brown (see Pl. XXV. fig. 3). In a lapillus one large pseudomorph of olivine is present, and is composed of a yellow material and calcite. Some portions of the former are dichroic, but the greater part has only a faint action on polarized light. The pseudomorph is surrounded by a thick coffee-brown border, with bands parallel to the boundary of the olivine. The whole is embedded in the dense black matrix of the lapillus, the brown and the black being part of the same mass and containing a few felspars in lath-shaped sections, a felspar often being embedded in both portions. Smaller similar olivine-pseudomorphs occur in the thin section. The brown border and black matrix appear very much like tachylyte. Altered augite occurs in small crystals or prisms. There are few vesicles: the larger of these are filled with calcite, the smaller with a yellow radio-fibrous material.

Brook Bottom, Outcrop 7.—This is mapped by the Survey as running across Water Lane, which leads from Brook Bottom to Tideslow Rake. I could only find it in the lane, where it is a dolerite exposed for about 90 yards, and in an adjoining field. In Brook Bottom, a valley, there is a rock exposed for a distance of about 50 feet and dipping 18° about 10° W. of S. It is bedded, and readily breaks into thin laminæ, parallel to the bedding. It consists of lapilli in a calcite-cement. The upper portion of the bed crops out about 130 yards north of Highfield House, and is exposed on the left-hand side of the road.

The bed of dolerite is 30 or 40 feet above the horizon of this tuff, the two being separated by beds of limestone. The tuff is about 20 feet thick. The horizontal section, sheet 70 of the Geological Survey, passes near this place; and another bed of toadstone should be added to make the section complete.

The tuff is generally laminated, but some portions are more compact and do not break up into laminæ. A specimen of the former (sp. gr. 2·64) consists of lapilli of a reddish colour, which, as well as the amygdaloids in them, have a thin yellow border. A large lapillus with very irregular outline occupies the greater portion of the slide. It contains olivine in porphyritic crystals

with a well-defined outline, and entirely altered to a network, or in some cases an opaque mass of iron oxide. The felspar is altered, and has only a feeble action on polarized light. It occurs in rhombic sections, one of which has an acute angle of 55°, and in lath-shaped sections which often contain portions of the base. The base is red in reflected, and a dense black in transmitted light, and, when magnified 200 diameters, some portions are seen to have a reddish tinge. The colour is probably due to iron oxide. Some portions of the base are structureless and free from minerals, and in other places a few hair-like crystallites are present. About half of the section of this lapillus consists of vesicles varying much in size; the larger ones especially are filled with calcite, which is fresh and shows the usual cleavages. The walls between adjoining vesicles are often very thin. Some vesicles are filled and others fringed with a light yellow substance, which also forms a border to the lapilli. It is grey in polarized light, and has but little action on it. The smaller lapilli are similar, and unbroken across the vesicles, being fully formed individuals, and not fragments of a compact rock. The lapilli are cemented by crystalline calcite.

A specimen of the more compact rock (sp. gr. 2·70) consists of lapilli varying in size from an inch downwards, of a dark-chocolate or of a green colour, in a cement of calcite. Under the microscope, some lapilli are of a light-green colour, and isotropic, and contain magnetite; others are similar to those in the specimen previously described. The olivine is altered to a light dirty-yellow material, and the cracks are filled with iron oxide. The outline is often clearly defined by a thin border of lighter material nearly transparent, and having hardly any action on polarized light. The base in some lapilli is a very dark brown, almost black (see Pl. XXIV. fig. 5), and in others a lighter brown, which, under a magnification of 200 diameters, is resolved into a number of crystallites with parallel extinction; they have a very feeble action on polarized light; the remaining base is isotropic. Numerous vesicles are filled with calcite, and all the vesicles have a very delicate outline.

Another similar specimen (sp. gr. 2·60) contains groups of a mineral in yellow grains. They are dichroic, with cleavage-cracks parallel to their length. The greatest absorption is parallel to the cracks, and the extinction is always parallel to them. This mineral is probably a rhombic pyroxene. Many of the lapilli are elongated in one direction.

Two blocks embedded in the tuff were examined microscopically. One of sp. gr. 2·74 is very amygdaloidal (calcite). Olivine occurs replaced by magnetite or ilmenite. There are few felspars, none of which are fresh; some of them are altered to calcite. The base consists of felspar-microlites and magnetite-grains, or a reddish-coloured substance. The other block (sp. gr. 2·68) is a very fine-grained rock, and much altered. It contains pseudomorphs of serpentine after olivine, felspar-microlites, and magnetite.

Litton, Outcrop 8.—This is mapped by the Geological Survey from

Tideswell Lane head across the top of Cressbrook Dale into the valley, and up the other side near Peter's Rock. It may be traced from near the lane head to the highest house in Litton, the 'Peep o' Day,' where it crosses the road. It is a bedded rock, and the layers vary very much in coarseness. Subangular blocks, some being 12 to 18 inches in length, are found in it, especially in the upper layers. There are also small pieces of a dark-coloured limestone. There are good exposures on the roadside, and in two gullies in the village. Climbing down into Cressbrook Dale, near Peter's Rock, we find an outcrop of what is probably the same bed. It consists of slabs 6 or 8 inches thick, which can be split into laminæ of about $\frac{3}{4}$ inch in thickness, and which at first sight appear like a fine-grained sandstone. This is no doubt what Farey[1] described east of Litton as toadstone "so perfectly stratified that laminæ almost thin enough for house slates might be got in it." These slabs are accompanied by coarser laminæ like those at 'Peep o' Day.' The bed may be traced up the hill in the opposite direction to the dip.

Proceeding down the valley, we pass about 15 to 20 feet of limestone and then come to a bed of dolerite between 10 and 20 feet thick. It is vesicular, and decomposed at the base, amygdaloidal and hard at the top, and compact towards the centre. It weathers hard and rough, the harder portions standing out in lumps of the size of a man's fist, and it breaks off into nodular pieces. In it are a vein and several nodules of quartz. The Geological Survey maps only one bed, but there are two, the lower one an olivine-dolerite, succeeded by 15 or 20 feet of limestone with fossils; and this in turn is overlain by a tuff, whose laminæ, varying in coarseness, denote variations in the character of the outburst.

A specimen of coarse tuff (sp. gr. 2·49) from this locality consists of lapilli in a cement of calcite. A lapillus contains olivine and augite-crystals, and one felspar, all altered to calcite, in a black base, containing vesicles filled with the same mineral. Others contain a few skeleton-crystals, probably felspar in a brown isotropic base, and others pseudomorphs of olivine in a dirty-brown base having slight action on polarized light. The vesicles are filled with calcite, or with a yellow, feebly double-refracting substance.

In a specimen from the exposure on the roadside at 'Peep o' Day' the lapilli are brown or grey, with green amygdaloids. Under the microscope only one lapillus contains any crystals, and these are pseudomorphs of olivine, felspars in very small lath-shaped sections, and magnetite. Some lapilli are a mass of vesicles filled with a material having radio-fibrous structure, and separated by thin walls of a generally isotropic base. These lapilli were originally more cellular than those from any other locality.

A much more altered specimen (sp. gr. 2·42) consists of black lapilli. A felspar-like mosaic, the pieces of which are too small to test by convergent light, fills the vesicles and the spaces between the lapilli. A specimen of the laminated tuff near Peter's Rock is

[1] 'General View of the Agriculture and Minerals of Derbyshire,' vol. i. (1811) p. 278.

much more altered. The lapilli vary much in size, they are yellow and brown in colour, often isotropic, but sometimes have a feeble action on polarized light. Some of them are entirely altered to calcite, others have a border of the isotropic material or of iron oxide, whilst the interior is composed of calcite. The vesicles are filled with calcite or with a clear felspar-like mineral, or again with a brown substance which gives a more or less regular cross in parallel polarized light. There are pseudomorphs of olivine in a few lapilli.

Four of the included blocks have been examined microscopically. Their specific gravity ranges from 2·72 to 2·49. They are very similar one to the other, so that a general description will suffice. The olivine is altered either to a brown, partly transparent and partly opaque substance, or to a clear felspar-like mosaic, the portions of which are not large enough to test by convergent light. The felspar occurs in small lath-shaped sections, which often have parallel extinction, and are often arranged with their long axes parallel to the sides of an olivine-section. A porphyritic crystal of felspar occurs which is very much corroded. The extinctions are 0° and 15° referred to the trace of the plane of composition; like many of the olivine-pseudomorphs, the crystal is surrounded by a darker portion of the base, with few or no felspars. The base is sometimes dark, and contains flakes, rods, or skeleton-crystals of magnetite. In other cases the base is a brown glass, more or less cloudy. The amygdaloids often have a ropy or knotted vermicular structure. The ropy part is calcite, or the clear felspar-like material, or both together; the interior is calcite, or the felspar-like mosaic. Sometimes iron oxide fills a vesicle.

Dove Holes, Outcrop 12.—This is mapped as toadstone by the Geological Survey, and well described in the Memoir as "a crumbly bed, pale grey with green specks, and contains pebbles of limestone, one of which was seen as big as a man's fist."[1] It is doubtful whether the rock is an igneous product. It is very much decomposed and lies between two beds of limestone: I have, however, been able to find a piece hard enough for a thin section. Under the microscope there are no signs of altered felspars or of altered lapilli; the rock has, in fact, the appearance of a clay. Were it not for the presence of rounded lumps of limestone similar to those at Ashover and in other tuffs, I should class it as a clay. If a tuff, it is so much altered that no sign of the original structure remains.

Monk's Dale, Outcrop 16.—This rock is situated where the road from Tideswell to Hargatewall crosses Monk's Dale. It is difficult to find, the outcrop being small, and for the most part covered with grass. In a field, near the footpath to Wormhill, may be found in the soil rounded pieces of limestone and of a rock like limestone containing a few small lapilli. An exposure, about a foot square, on the road to Hargatewall, consists of coarse and fine tuff,

[1] Geol. Surv. Mem., N. Derbyshire, 2nd ed. 1887, p. 21.

containing limestone-pebbles. The limestone dips rapidly down the hill, and this rock disappears underneath it. I could not find the tuff on the eastern side of the valley.

A specimen of the finer-grained rock (sp. gr. 2·66) is a grey, compact rock, consisting of dark amygdaloidal lapilli in a limestone or calcite-cement. The lapilli are small, and are sometimes surrounded by a dusty border. Some contain felspars often untwinned, which extinguish parallel with their length, are almost entirely fresh, and are not seldom arranged with their long axes parallel. Others contain a pseudomorph of olivine, which occupies nearly the whole of a lapillus. The groundmass is light green in ordinary light, and isotropic. Some lapilli contain only amygdaloids, which are generally isotropic. (See Pl. XXV. fig. 2.)

Another specimen (sp. gr. 2·63) consists of green and yellow lapilli larger than in the preceding, with dark green amygdaloids. Olivine and felspar occur as in the previously described specimen, but the felspars are partly altered. There are small grains of calcite, and a yellow serpentinous substance, which may be altered augite. The groundmass is clear yellow-green in ordinary light, with little action on polarized light. Some parts are darker patches containing magnetite-dust or globulites. The rock appears to have undergone alteration. Some of the vesicles are filled with calcite, others with the clear yellow material, which is black or dark green in a hand-specimen. This material consists sometimes of fibres radially arranged, and shows a black cross in polarized light; in other portions it possesses little structure, and has hardly any action on polarized light. Some of the amygdaloids are bordered with a dark material, which under a magnification of 600 diameters, is seen to consist of globulites. The portions in which they occur remain extinct between crossed nicols. Circular patches of globulites, or cumulites, also occur in the groundmass. The cement is a very light-brown substance, and is composed of small granules ($\times$ 600 diam.), in which pieces of calcite and also pebbles of a more transparent rock containing organisms are embedded. The cement of the first-described specimen is similar, but contains no organisms. (See Pl. XXV. fig. 1.)

Ravensdale Cottage (*in Cressbrook Dale*), Outcrop 18.—It is exposed in a small cutting in the side of the hill, on the left of the path, in sight of the cottages, and near the gate leading into a field. The rock is very much decomposed, traversed by numerous veins of calcite, and contains small pieces of limestone. It consists of red lapilli in a brown cement. Under the microscope the lapilli are of a dirty-brown colour, and often altered to a brown calcite, or to clear calcite with a border of iron oxide. Some of the smaller lapilli are yellow, and have a feeble action on polarized light: they contain no crystals. There are some vesicles filled with calcite. The cement is a dirty calcite. The rock is a much altered tuff, mainly composed of what were probably glassy lapilli (sp. gr. 2·48).

Miller's Dale Station, Outcrop 19.—This bed is mapped as running from Cressbrook through Taddington and Chelmorton to Great Low. The rock is generally an olivine-dolerite, and in places an olivine-basalt. East of Miller's Dale Station a cutting has lately been made for a tram-line, which runs from the down line of railway past the bottom of several large limekilns to the large limestone-quarry above the toadstone.

The junction of the two rocks is well exposed. Resting on the limestone are about 1 or 2 feet of a clay and a decomposed rock; above this the rock becomes hard and breaks readily into laminæ. It then becomes harder and less platy, and is altogether about 2 feet thick. It is very fine-grained and of a drab colour. Examined under the microscope, it is seen to be a crystalline limestone with few, if any, organisms, and containing small lapilli. These are often clear and glassy (isotropic), with globulites and sometimes a felspar having parallel extinction. Sometimes they are brown, and contain hair-like crystallites, the whole being isotropic. Some are bordered with iron oxide. A few fragments of felspar showing a biaxial figure, and pieces of calcite twinned like a felspar, probably pseudomorphs, occur in the limestone. These are in a specimen 6 inches above the clay (sp. gr. 2·46).

A specimen 9 inches above the clay (sp. gr. 2·52) is similar, except that the lapilli are smaller, form a smaller proportion of the whole mass of the rock, and are often altered to calcite.

A block of amygdaloidal rock (sp. gr. 2·62) embedded in this ashy limestone contains pseudomorphs of olivine, large and small felspar-laths, skeleton-crystals and rhombic sections of felspar in a dark base, which is partly isotropic. Above the ashy limestone we find a large, irregular-shaped mass of hard, grey, amygdaloidal rock several feet in thickness (sp. gr. 2·58), similar to the block previously described, many of the felspars in it having parallel extinction; there is also a felt of crystallites with magnetite-skeletons in the partly glassy base. About 9 feet above the clay this rock appears more like an ordinary dolerite, and under the microscope the felspars are seen to be larger, more numerous, and much less altered, and there is a less amount of base.

Above this dolerite is a bedded coarse-grained tuff, the lapilli being dark, with amygdaloids of calcite. Under the microscope the lapilli may be divided into two kinds: (*a*) pseudomorphs of calcite after olivine, felspar-laths mostly altered to calcite, and patches of calcite in a dark groundmass coloured with iron oxide; (*b*) yellow lapilli, having little action on polarized light, and sometimes bordered with iron oxide, some containing no crystals, and others felspar-laths. The cement often consists of the same yellow substance with magnetite-dust. The limekilns, and the roads to them, are between the coarse tuff and the spheroidal dolerite above it, so that the junction is not seen.

Several hundred yards east of the kilns is another quarry in which the ashy limestone and the dolerite above it may be seen; both are much more decomposed than in the exposure previously described.

The upper dolerite may be traced for several miles. I cannot say whether this tuff is merely local or underlies the upper dolerite throughout its extent, as I have been unable to visit the district since I found the tuff.

We have here, resting on the ordinary limestone of the district, an ashy limestone, denoting a slight fall of volcanic ash during the deposition of the limestone. This is followed by a lava-flow, that again by a shower of coarse ash, and the whole by a lava-flow, which extends over a large area.

Cracknowl House, Bakewell, Outcrop 34.—There is no good exposure. In the valley below Cracknowl House, small patches of red soil are seen on the eastern side. They contain small lumps of the rock, many of which would not be seen except for the rabbit-burrows. The rock is much decomposed: the lapilli are very much altered and of a red colour, containing here and there a much altered felspar-lath and iron oxide. An included block (sp. gr. 2·44) contains olivine replaced by a mineral which gives aggregate polarization, probably felspar or quartz, and felspar-laths of two generations, the smaller ones being often curved, bifurcated and ragged, and frequently giving parallel extinction. The groundmass has a slight action on polarized light. Quartz sometimes fills the vesicles.

Ember Lane, Outcrop 39.—Starting at the Bonsall end of Ember Lane, we meet with the tuff on the left-hand side soon after the turn from N.E. to E. It is exposed for about 200 yards in the bank, and in a field on the left. It might at a little distance be taken for an ordinary limestone, but, on closer examination, is found to be a limestone with large lapilli embedded in it, which stand out in relief when the rock is weathered. Specimens abound in the walls. Proceeding up the lane it passes into a bedded ash, which is seen to contain pebbles of limestone just before we reach a small shed. It is difficult to make out the bedding, but if the dip corresponds with those of the limestone taken at Cromford, and between that place and this locality, the ash lies above the ashy limestone, and is succeeded by a dolerite-flow seen near and beyond the shed. It is vesicular, and the olivine and felspars are much altered. If these conclusions as to the dip are correct, we have here limestone containing many lapilli, or an ashy limestone, passing upwards into a bedded ash, and this succeeded by a lava-flow. This dolerite covers a large surface on Masson Hill, and is an olivine-dolerite containing in places augite in grains, and in other places augite in ophitic plates.

Mapping the toadstone from the 1-inch map on to the 6-inch (which is not a very accurate method, as some of the details must inevitably be exaggerated on the former scale), it will be found that the toadstone-outcrop passes through places where the dolerite and ash occur, but not through those where the ashy limestone occurs. The latter is on an inlier (assuming the dip previously mentioned to have been correct) of limestone between the 700 and 900-feet

contour-lines. On another small inlier of limestone, between the 900 and 1000-feet contour-lines near Low Farm, I found in the walls pieces of a similar ashy limestone. I have been unable at present to look carefully for any outcrop.

At Jughole Wood the dip is northerly; between there and Low Farm it is north-easterly. It is likely that the anticlinal seen in the Derwent Valley, opposite the High Tor, passes near Low Farm. If this be so, there may be two outcrops of limestone-tuff forming parts of the same bed under the dolerite, and we should not expect to find any signs of this bed of tuff in other parts of the outcrop of toadstone, because they consist only of the upper part of the bed.

A specimen of the ashy limestone (sp. gr. 2·57) contains also pebbles or pieces of limestone. Examined under the microscope, it consists of lapilli in a limestone containing organisms. A large lapillus contains olivine (altered to a green-and-yellow dichroic material) and felspars with nearly parallel extinction, in a dusty brown base. Others contain vesicles filled with a substance having fibro-radial structure, lighter in colour than the remaining parts of the lapilli, which are mostly isotropic. Sometimes the outer portions of the lapilli are clear yellow and isotropic, the inner portions being crowded with black enclosures and giving bright colours in polarized light; in some cases they are fibrous, the fibres being in bundles. Many amygdaloids occur, showing the black cross as the nicols are rotated. Some vesicles are filled with calcite, some with a black material, and others with the cement of limestone. The lapilli are irregular in shape, and are often very delicate in form. They appear to have fallen into a limestone in process of formation, or into a limestone-paste.

Another specimen (sp. gr. 2·61) contains a large lapillus about 1 inch in diameter. Olivine-pseudomorphs and felspar-laths occur in a black base. There is a large quantity of crystalline calcite which may be altered portions of the base, or which has more probably filled in the numerous and large vesicles. Often half a dozen patches which do not communicate have the same optical orientation, extinguishing together, and contain parallel sets of cleavage-cracks. In some parts the calcite is more plentiful than the black base, but the latter is always a connected whole, the walls of the cells being very narrow, except in a few cases where we have a smaller lapillus in a vesicle of the large piece. Other lapilli are of a dirty brownish-yellow colour, isotropic in parts, and in others having a roughly spherulitic kind of structure. The cement is a reddish-coloured substance which contains small pieces of limestone with organisms in them, and also probably small fragments of organisms. Here the lapilli are mixed with fragments of already formed limestone, and do not appear to be embedded in a limestone-paste as those in the previously described specimen.

Grange Mill, Outcrop 46.—This is well exposed near the junction of the roads to Winster and Ible, beyond the top of the Via Gellia. The exposure is for some 15 yards on the roadside, and may be traced in the fields on the right for about 100 yards.

Opposite the Mill the structure is distinctly spheroidal. Farey says that it has a "boily and nodular texture"[1] here and near Bakewell. At the latter place the rock is a dolerite, but here it is a tuff. The spheroids vary from 2 feet down to 1 inch in diameter. Some of the larger ones have several coats or shells, and others are divided into three or four pieces by irregular joints. At first sight the rock might easily be taken for a basalt, but a closer examination shows the spheroids to be composed of a grey rock with green spots, which under the lens are seen to be amygdaloidal lapilli. Prof. Bonney mentions a similar instance of spheroidal structure in a volcanic ash in the Italian Tyrol, which at a short distance might readily be mistaken for a decomposing basalt.[2] This is the only occurrence that I have found of spheroidal tuff in the county. There are spheroidal blocks in the tuff near Kniveton, but these are very different (see outcrop 56, p. 638).

Proceeding towards Winster the rock is more massive and often laminated, contains pebbles of limestone, and also a small bed or else a collection of blocks of dolerite.

Near Shothouse Spring there is at least 10 feet of tuff exposed. The layers vary much in coarseness and thickness, and there is no spheroidal structure. The spring issues from the junction of the tuff and the limestone above it, flowing along the top of the tuff-bed. The latter is almost impervious to water, and when a specimen is dried it is seen to be made up of decomposed lapilli. About 100 yards farther north is a limestone-quarry. A bed in it thins out from several feet in thickness, and consists of lumps of a reddish-coloured limestone containing a few small lapilli.

In a specimen from opposite the Mill (sp. gr. 2·64), the rock consists almost entirely of lapilli. They vary in size and shape, and are very tender and delicate, often having several branches. In reflected light the lapilli and vesicles appear to be coated with a porcelain-like grey material, which makes up the bulk of the rock. In transmitted light a coffee-brown colour borders the larger lapilli, coats the inside of some of the vesicles, and constitutes the whole of the smaller lapilli. It is isotropic, and when magnified 600 diameters is seen to contain small globulites and is often bordered by a thin layer of an almost black colour, probably magnetite (see Pl. XXIV. fig. 6). The inner portions of the larger lapilli and the vesicles consist of a light yellow material which has a feeble action on polarized light. The structure is fibrous, and the fibres are often in bundles, but it sometimes shows aggregate polarization, and is often bordered by a band of globulites. The interior of some lapilli consists of crystalline calcite and serpentine. Felspar occurs very seldom. There are only a few lath-shaped sections, seldom twinned, and all (except one of them) extinguish parallel or nearly parallel with their length. There is a very little calcite filling some of the space between the larger lapilli: the remainder of the space is

[1] 'Agriculture of Derbyshire, etc.' vol. i. (1811) p. 278.
[2] 'On Columnar, Spheroidal, and Fissile Structure,' Quart. Journ. Geol. Soc. vol. xxxii. (1876) p. 140.

occupied with smaller lapilli. In some other specimens there is a felspar-like material here and there in the lapilli which is biaxial and may be secondary albite, and the outer vesicles of a larger lapillus sometimes contain smaller lapilli.

A section cut from one of the spheroids (sp. gr. 2·45) shows a similar structure, the only difference being that the brown lapilli are not quite isotropic, and contain more skeleton-crystals of felspar and crystallites. Another specimen consists of yellowish-green lapilli, containing no crystals, and with a thin black border. The vesicles are filled with calcite surrounded by a black border, or with the black material only. Under a high power they often consist of masses of globulites, and while sometimes free from colour are in other cases stained by iron oxide. A section from a bed of fine tuff near Shothouse Spring (sp. gr. 2·46) consists of small lapilli in a cement of calcite. They are water-clear, yellow, brown, or black with magnetite, and generally isotropic. Several of them contain what may be possibly pseudomorphs of olivine. The amygdaloids consist of fibrous material radially arranged.

A specimen of the rock from the quarry (sp. gr. 2·66) consists of a limestone containing amygdaloidal lapilli altered to calcite, and bordered with iron oxide. The limestone contains hæmatite. Of the dolerite, two specimens have been examined microscopically. One (sp. gr. 2·78) contains pseudomorphs of serpentine after olivine, fresh augite in small grains, and unaltered plagioclase. The other is a similar rock but more decomposed, none of the minerals being fresh (sp. gr. 2·61).

Hopton, Outcrop 53.—This exposure is opposite Hopton Hall grounds, on the road from Wirksworth to Carsington, where that from Hopton Wood joins it. On a cursory examination the rock might be taken for a brecciated limestone, due to the decomposition of the calcite which forms the cementing-material of the lapilli. It is described by Farey [1] as a 'brecciated toadstone,' and in the Survey Memoir as "a very coarse brecciated ash, with beds of dolerite." [2] The fragments vary much in size, from 2 feet in length down to the size of a pea and smaller. Some are more or less rounded, but the majority are angular. Where the surface of the rock is weathered, the larger angular pieces project and give it a rough appearance. I have been unable to find any trace of a dolerite sheet. Wherever larger pieces of rock are seen, they are found to be included blocks. Sometimes a face of the rock extending for several yards will look like a massive rock, but when broken into proves to be made up of small fragments. The rock is exposed for about 200 yards along the road to Hopton Wood, and the lower parts are made up of the same material as the upper. The finer-grained parts in a hand-specimen are seen to consist of a black fine-grained dolerite, with felspars similar to those of the larger blocks, and of green lapilli.

A thin section from a piece of the dark rock, which measures $2\frac{1}{2} \times 2 \times 2$ inches (sp. gr. 2·68), contains olivine, augite, felspar, and

[1] *Op. jam cit.* p. 278. [2] P. 24.

magnetite. The olivine is entirely altered to cloudy calcite and serpentine. The augite is in small irregular prisms and in porphyritic crystals, and generally unaltered. The latter often contain portions of glassy material, and are sometimes cracked; groups of two or four individuals and twins are frequent. The felspar, unaltered, occurs in porphyritic crystals which often possess zonal structure. The lath-shaped sections vary in size. Symmetrical extinctions of twins on the albite plan give angles of $\frac{35^\circ}{37^\circ}$, $\frac{34^\circ}{30^\circ}$, $\frac{27^\circ}{32^\circ}$. The first may be referred to the anorthite group, and the two last perhaps to the labrador-anorthite group. Many of the smaller ones extinguish nearly parallel to their length. The groundmass is black and nearly opaque, and contains magnetite in skeleton-crystals.

Another specimen (sp. gr. 2·59) consists of five or six pieces of the black rock about ¾ inch in diameter; the space between them is filled with small fragments of a light-green rock and very little calcite. Three sections were cut from this specimen. The first consists mainly of one of the larger pieces of black rock. The olivine is altered to calcite with serpentine along the cracks; the largest crystal measures $\cdot 85 \times \cdot 5$ millim., and they are all well bounded. The augite is scarce, occurring in small grains, prisms, and porphyritic crystals. The felspars vary from 1 millim. in length to less than ·04 millim. The ends are sometimes jagged, and sometimes bounded by crystalline faces: portions of the groundmass are included in these felspars. Symmetrical extinctions of a twin give the angles $\frac{31^\circ}{32}$. They are often arranged in groups, and sometimes two are parallel and nearly touching one another, or touch through part of their length as if they had been pushed up to one another. This has been noticed in lapilli by A. Penck,[1] and their juxtaposition is attributed by him to the sudden cooling of the glassy base. Some of the small crystals are arranged in the form of a cross. The groundmass is a dense black in ordinary light, with the ends of felspars terminating in fine splinters merged in it. The black mass contains a few hair-like microlites, ·001 millim. in breadth, which extinguish parallel with their length. In another portion the groundmass is lighter, and consists of a felt of the microlites. Irregularly-shaped and elongated vesicles are filled with calcite. The boundary of the piece towards the inner part of the slide is irregular, and may be compared to the forms of bays and promontories on a map. The felspars near the border are always wholly contained in it and do not project from it, whilst on the edge of the slide, where it is broken by grinding, the crystals are broken across. These appearances denote, I think, that—before grinding—the piece was a complete individual. It is bordered by calcite, in which are smaller portions of the rock with black groundmass, also a few small felspar-crystals and fragments of augite, and small pieces of a very light dirty-brown rock containing felspar-crystals in a glassy base; see Pl. XXV. fig. 4. The second section from the same specimen

[1] 'Studien über lockere vulkanische Auswürflinge,' Zeitschr. deutsch. geol. Gesellsch. vol. xxx. (1878) p. 97.

contains one piece of the rock with black base; the pseudomorphs of olivine and the augite and felspar contain more of the groundmass than in the first case. The numerous lapilli are of a light-yellow colour, and so completely isotropic that they are indistinguishable from the black rock under crossed nicols. Magnetite-dust is scattered sparsely through them, and they contain small augite-grains and prisms and felspar-laths, but no olivine or microlites. Felspar and augite occur singly in the calcite-cement.

The third section consists of lapilli of the black rock with smaller felspars and augite-prisms, and of yellowish-green and brown lapilli in a cement of crystalline calcite. The latter contain one fresh olivine-crystal and some larger ones, replaced in part by a fibrous brown substance. The augite is in very small prisms and in small porphyritic crystals. The felspars are numerous and vary in size, often having jagged ends. They are frequently grouped, and in some lapilli they are bordered with magnetite. The groundmass is in most cases isotropic, in some cases a slight action on polarized light is observed, and there are a few circular spots which show a more or less regular black cross under crossed nicols. These were probably vesicles originally. Sometimes the groundmass is cracked, and the cracks are filled with magnetite. They do not run through the crystals, except in very few cases; the same crack is continued on opposite sides of a felspar-crystal, or when it touches the end turns off at an angle. There is no perlitic structure. In some lapilli a certain amount of alteration appears to have taken place, and some have a dirty colour which is probably due to iron oxide.

Lapilli of another specimen are of a brown colour. In ordinary light they are differentiated into a darker brown portion and into a lighter dusty one: the lighter part often forms what look like cracks in the brown part. In polarized light the whole is isotropic.

Kniveton, Outcrop 54.—This is a small outcrop in an inlier of Mountain Limestone, exposed near the corner of a field a short distance from the footpath which runs from Lea Cottage to Tissington Wood Farm. The exposure is about 6 feet deep and 10 feet in length. The rock is hard, and has a rough bedding along which it breaks more easily than in any other direction. It is evidently a fragmental rock, and does not contain spheroidal blocks such as those of outcrop 56 (see p. 638).

A large portion of a slide (sp. gr. 2·51) is occupied by one lapillus, which is like the first block described from outcrop 56. It is exactly similar in microscopical structure. In one amygdaloid the felspar-like mosaic consists of separate portions large enough to show a biaxial figure in convergent polarized light. The slide contains several other similar large lapilli, with a more altered base, and the amygdaloids in them contain smaller lapilli. Some of the smaller lapilli in the remainder of the slide contain no crystals, and are often altered to the felspar-like material. The cement is calcite.

Another specimen of tuff (sp. gr. 2·54) is made up of lapilli in a cement of crystalline calcite. The lapilli are of two kinds:—(*a*) Similar to the blocks in outcrop 56, and (*b*) light green, almost isotropic, containing globulites, or composed of the felspar-like material. The vesicles are filled with calcite.

A third specimen (sp. gr. 2·50) is similar to the preceding, except that it contains lapilli of a yellowish-green glass with crowds of globulites and a few felspars giving lath-shaped sections. The globulites are often arranged in the form of a felspar-lath or of a rhombic section. The vesicles are filled with calcite or the felspar-like material with radio-fibrous structure.

Kniveton, Outcrop 56.—Lies between Woodeaves Farm and Lea Hall in a large field containing a limestone-quarry, and through which the brook runs in a southerly direction. The field forms the eastern side of the valley, and on the steep slopes the rock may be seen in several places. In the upper part of the bed it is soft and easily broken, and contains small pieces of limestone. There are also included blocks of a very hard light-coloured rock, which is studded with calcitic and dark green amygdaloids, and in this hard rock minute felspars may be seen with a lens when the rock is wetted.

In the steep right-hand bank of the stream is a good exposure 10 or 12 feet high, without vegetation. It is almost entirely made up of blocks more or less rounded, varying in size from 10 inches to about 1 inch in diameter. They appear like spheroids embedded in a fine ash. When extracted, the ash adheres to their outer surface. In places the ash predominates, and when broken up is found to contain smaller spheroids of the harder and compact amygdaloidal rock. The ash is made up of small lapilli, the amygdaloids in which are well seen when the rock is wetted. Twenty feet higher in the series the ash is exposed, and contains smaller and fewer amygdaloidal blocks. The whole exposure is about 30 feet thick.

A section from one of the included blocks (sp. gr. 2·72) contains olivine, altered partly to calcite, and partly to a felspar-like mosaic often containing pyrites. The felspar occurs in rhombic and in lath-shaped sections. Some have parallel extinction and some are not twinned. I have been unable to obtain twins with symmetrical extinction. Three give the angles 23° and 27°, 20° and 30°, 25° and 50°, referred to the trace of the plane of composition. The ends are often indented, and some of the felspars contain globulites. There are also microlites, which extinguish parallel to or at a small angle with their length. They are sometimes curved. The base is a very feebly-refracting felspathic substance, sometimes brown with globulites or magnetite, arranged parallel to the sides of the olivine-pseudomorphs. The amygdaloids are large, numerous, and close together. The felspars near them are often arranged tangentially to the almost circular amygdaloid boundary, and where the wall is very narrow it is almost entirely formed of one or two felspars; see Pl. XXV. fig. 6. Calcite generally fills the vesicles, and sometimes has an outer zone of feebly double-refracting grey material whose fibres are roughly parallel to the radii of the zone.

Another block (sp. gr. 2·48) contains similar minerals, but the base is often a dense black, sometimes a dark grey, and isotropic. The vesicles are filled with calcite or with the felspar-like mosaic, or both. Some vesicles contain lapilli without crystals, which are altered to a mosaic in the inside, and bordered by a brown material which contains globulites, is almost isotropic, and in reflected light has a dirty porcellanic appearance. At one edge of the slide is a large group of these lapilli in a felspar-mosaic, which is probably an amygdaloid.

A section from another block (sp. gr. 2·59) consists of a similar rock bounded by a calcite-cement, which contains small glassy lapilli without crystals, some of them altered to calcite. These lapilli are probably portions of the ash adhering to the block.

In another block (sp. gr. 2·70) the felspars sometimes appear to resemble twins, but both parts invariably extinguish together and are separated by a portion of the base containing globulites. The smaller felspars are often arranged in bundles and plume-like forms, radiating from a point so as to form a small sector of a circle. There is very little base, consisting mainly of globulites in glass (isotropic).

In a thin section of tuff (sp. gr. 2·40) the lapilli vary from a colourless, through a yellow to brown or dark-brown glass. A few have a slight action on polarized light. The vesicles are of the same glassy substance, and are often surrounded by a border of globulites or iron oxide, or both. One large lapillus only contains a few felspars in lath-shaped sections altered to calcite.

Another thin section (sp. gr. 2·44) contains lapilli, very irregular in shape and amygdaloidal. In some cases they are a mass of amygdaloids with narrow walls. There are a few probable pseudomorphs of olivine, but no felspar. A lapillus has a black base containing pale yellow vesicles with a darker yellow border; they have a bright action on polarized light and a radio-fibrous structure. Other lapilli are of dusty dark-brown or yellow glass, and others more like tachylyte, with sometimes a slight action on polarized light. Some lapilli are altered in part to calcite, and in part to a fine felspar-like mosaic. When entirely altered to calcite, the lapillus is traversed by cracks which are filled with iron oxide. Calcite forms the cement between the lapilli.

A third specimen (sp. gr. 2·46) contains lapilli with olivine altered to calcite, and felspar in small lath-shaped sections, crowded together and often in bundles, in a base partly black and partly transparent and isotropic. Other lapilli are of clear and transparent glass, containing strings and rods of globulites or longulites. Some are altered to a felspar-like material which has very feeble action on polarized light.

Ashover, Outcrop 59.—This occurs in a small inlier of Mountain Limestone which has been brought up by an anticlinal. Exposures are best seen in two cuttings which have been made to lime-kilns on the right of the road from Milltown to Ashover. The rock is less weathered in the cutting nearer Milltown. In a small cave on the

right the layers are well seen. Those forming the roof become detached, and fall to the floor by their own weight. They are about 1 inch thick. In the roof is a somewhat rounded block, measuring $7 \times 5 \times 4$ inches, of decomposed dolerite. The olivine is replaced by iron oxide, and the felspars are much altered. Under the microscope no augite is seen, though it cannot be said that it was never present. I also found a nearly spherical block, 6 inches in diameter, of a similar dolerite containing amygdaloids. Many limestone-pebbles are found in this tuff.

In the cutting near Ashover the thickness of the exposed beds is about 16 feet. Near Fall Mill a shaft was sunk 70 yards through this rock.[1] The rock dips east under the limestone; for about 2 yards below the junction it is powdery, and passes into a more or less laminated rock traversed by numerous veins of calcite and containing fragments of chert, limestone, and dolerite. It is purple and green in colour. The rock is so decomposed that it is difficult to obtain a good piece for a thin section.

A specimen (sp. gr. 2·49) consists of dirty-looking green lapilli in a cement of calcite and grey material. Under the microscope the lapilli are light and dark brown or very pale green, all isotropic. Some contain pseudomorphs of olivine, often in groups; few contain felspar-laths with parallel extinction. The vesicles are generally filled with calcite.

Another specimen (sp. gr. 2·46) consists of green lapilli with dark green amygdaloids in a red cement. Under the microscope the lapilli are very light green. They contain no crystals, with the exception of two which have a few felspars. In plane-polarized light the groundmass gives a lively play of colours, and sometimes black brushes opening out into rude hyperbolæ, not unlike those seen in a biaxial crystal in convergent light.

Some are elongated and have elongated vesicles, which are filled with a material similar to that of which the lapilli are composed, and show a black cross due to radial arrangement of fibres. The lapilli are often bordered with a black substance, and some are entirely black throughout. The cement consists of smaller lapilli, often isotropic, with a little calcite.

A third specimen (sp. gr. 2·35) contains lapilli which vary greatly in size. The majority are very small and fantastic in shape, contain no crystals, and are generally isotropic. Some are altered to calcite, except on the outside border. (See Pl. XXV. fig. 6.)

The fantastic outlines of the lapilli show that they cannot have been formed by the trituration of a compact lava. They are differentiated from the substance of the solid rock in the dolerites and basalts of the district by their preponderating glassy base more or less altered, the presence in it of a large number of skeleton-crystals and crystallites, and by their numerous amygdaloids. Their form and structure prove that they are true volcanic ejectamenta, and not the product of broken-up lava-streams. They vary in magnitude from very small fragments up to about the size of a pea.

[1] Geol. Survey Mem., N. Derbyshire, 2nd ed. 1887, p. 154.

The thin sections containing lapilli may be divided into two classes, olivine-bearing and olivine-free. (The olivine is seldom fresh.) Augite occurs in very few cases of the former (mostly in outcrop 53) and in none of the latter.

The lapilli of the first class are composed of a glassy base with the addition of either:—

(*a*) Olivine, augite, and plagioclase; or
(*b*) Olivine and plagioclase; or
(*c*) Olivine, plagioclase, and crystallites; or
(*d*) Olivine.

The second class are composed of:—

(*e*) Plagioclase in a glassy base; or
(*f*) Plagioclase and crystallites in a glassy base; or
(*g*) Glass only.

They sometimes contain magnetite in addition to the above mineral.

In some outcrops we have only *a*, *b*, *c*, *d*, or *g*, as (*a d g*), etc., whilst in others we have such combinations as (*a d g*), (*b f g*), or (*d e f g*). Felspar is the prevailing mineral in them, and augite occurs the least frequently. These results differ from those obtained by Penck[1] for the crystalline secretions in basalt-tuff. He classes them into (1) Plagioclase and olivine; (2) Augite, olivine, and magnetite; and (3) Olivine and magnetite.

The cement is crystalline calcite, or a paste consisting of smaller lapilli (and probably their decomposition-products), or a limestone paste. There is a very small admixture of non-volcanic material. This is almost entirely represented by the more or less rounded lumps or pebbles of limestone, which sometimes contain fossils. In outcrops 46 and 59 blocks of olivine-dolerite are found in the tuff. In the remaining outcrops, except in 16, 18, 39, and 54, I have found blocks with a more or less glassy base belonging to the olivine-bearing class, and, like the lapilli of that class, they may be divided into *a*, *b*, *c*, and *d*. In outcrop 56 the blocks have a roughly spheroidal shape.

The specific gravity of the blocks is greater than that of the lapilli-tuff in which they are embedded, and if we compare blocks and lapilli-tuff of similar microscopical structure from different outcrops, we shall notice that the specific gravity of the blocks is always greater than that of the tuff, and that the blocks in their turn have a lower specific gravity than the dolerites of the district.

It is interesting to compare the Derbyshire tuffs with those of Carboniferous age in the Firth of Forth Basin, described by Sir Archibald Geikie.[2] In the Scottish tuffs no microlites were found such as those which are present in some modern volcanic tuffs. In Derbyshire crystals of augite and felspar are found in the crystalline cement of some of the tuffs. In the Scottish rocks the lapilli consist

[1] 'Ueber Palagonit- und Basalt-tuffe,' Zeitschr. deutsch. geol. Gesellsch. vol. xxxi. (1879) p. 571.
[2] Trans. Roy. Soc. Edin. vol. xxix. (1880) pp. 513–516.

chiefly of rounded or subangular fragments of the lava of the district in which the tuff lies, and many of them do not differ in any respect from the substance of the solid rock as seen in sheets or dykes at the surface. The Derbyshire lapilli are seldom rounded or subangular fragments, but answer rather to those of palagonite from Kilmundy Hill and other localities, and like them have no counterpart amongst the lavas erupted at the surface.

EXPLANATION OF PLATES XXIV. & XXV.

[The figures are all photographed from the microscope in ordinary light. The first four are magnified 40 diameters, and the last eight 50 diameters.]

Plate XXIV.

Fig. 1. Peak Forest pseudomorph after olivine, Outcrop 4. Near the top of the figure is a small nucleus of fresh olivine, surrounded by a feebly double-refracting substance, of which the nebulous patches are also composed. The pseudomorph along the cracks is yellow and slightly dichroic; the portions showing cleavage are yellow for rays vibrating parallel to the short axis of the polarizer, and green for rays at right angles to that axis. Both portions polarize in bright colours, and extinguish parallel with the length of the original olivine.

Fig. 2. Potluck pseudomorph after olivine, Outcrop 60, with cleavage parallel to its length, and showing the position of the cracks in the original olivine. It is enclosed in ophitic augite. It is yellow for rays perpendicular to the short axis of the polarizer, and orange-brown for those parallel to that axis.

Fig. 3. Potluck pseudomorph after olivine, Outcrop 60. The greater portion is yellow, with traces of cleavage parallel to its length. It is dichroic, and polarizes in colours of the first and second orders. Two smaller portions on the left are cut parallel to the cleavage-planes and show an acute bisectrix (negative) with a very small axial angle. To the right are plagioclase-laths in ophitic augite.

Fig. 4. Potluck pseudomorph after olivine, Outcrop 30. The double refraction is strong, and the polarization-colours are similar to those of biotite. It is green for rays vibrating parallel to the short axis of the polarizer, and pale yellow for those at right angles to that axis. The cracks are filled with iron oxide. Above and below it are two similar, but smaller pseudomorphs.

Fig. 5. Portion of a large lapillus from Brook Bottom tuff, Outcrop 7. In the left-hand portion the felspars are broken across. They are embedded in a dense black groundmass, which contains several amygdaloids of calcite.

Fig. 6. Lapillus from Grange Mill tuff, Outcrop 46. The internal portion has a slight action on polarized light. The border is of a coffee-brown colour and contains globulites. Smaller lapilli make up the greater portion of the rock immediately surrounding it.

Plate XXV.

Fig. 1. Tuff, Monk's Dale, Outcrop 16. On the right is part of a lapillus with an isotropic base. On the left is a fragment of limestone containing organisms.

Fig. 2. Tuff, Monk's Dale, Outcrop 16. Amygdaloid lapillus with an isotropic base. Some of the crystallites have no action on polarized light, others have a slight action and extinguish parallel to their length.

Fig. 3. Lapillus from Castleton tuff, Outcrop 1, containing several felspars. It is of a black colour and cracked. The cracks are filled with, and the lapillus is bordered by a light yellow material, probably an alteration-product. The cement is crystalline calcite.

Fig. 4. Augite entirely embedded in the calcite-cement of the Hopton tuff, Outcrop 53. It extinguishes at an angle of 26° with the cracks which run parallel to its length. On either side of it are yellow lapilli which contain felspars, and are isotropic.

Fig. 5. Ashover tuff, Outcrop 59. The lapilli contain no crystals. The tuff is fine-grained, and the cement consists of smaller lapilli with a little calcite.

Fig. 6. Part of a spheroidal block in Kniveton tuff, Outcrop 56, showing three adjacent amygdaloids separated by thin walls consisting of felspar, magnetite, and interstitial matter. In the narrowest portions the felspars are arranged tangentially to the boundary of the wall.

Discussion.

Sir Archibald Geikie, in complimenting the Author on the completion of a laborious and valuable piece of work, alluded to some of the striking points of resemblance between the microscopic structures of the Derbyshire volcanic rocks and those of the Carboniferous series in Central Scotland. It appeared to him, however, that the petrography of the region would not be adequately understood until the history of the volcanic phenomena had been investigated in the field with far more minuteness than had yet been attempted. Having recently for the first time visited the 'toadstone' area, he was able fully to confirm the suspicion which he had long entertained, that the story of these volcanic rocks was far more varied and interesting than had been supposed. He had often wondered why none of the vents of discharge had been detected in a region so deeply trenched with valleys as Derbyshire. But in the course of a few days he succeeded in discovering at least six of these vents. They are filled with coarse unstratified agglomerate, and are sometimes traversed by dykes or veins of dolerite or basalt. As admirable examples, he described two such vents at Grange Mill, west of Matlock Bath, where they rise through the limestones and are flanked with a band of finely-bedded tuff, which may mark the material ejected from them. Vents are found from the extreme north to the extreme south of the limestone area, and even traverse the Yoredale rocks.

While many of the toadstones are true lava-streams which, either with or without fragmental accompaniments, were poured out over the floor of the Carboniferous Limestone sea, he felt tolerably certain that some of them are intrusive sills. In internal structure they present a close resemblance to the usual type of Carboniferous sill in the basin of the Firth of Forth. At one locality near Peak Forest he found that the limestone overlying one of these sheets is marmorized near the contact. Again, in Tideswell Dale, as was well known, a band of clay underlying another similar rock has been made columnar to a depth of 9 feet.

In his rapid traverses of the ground, the speaker had the great advantage of the intimate local knowledge of the Author of the paper, who had kindly guided him to the sections which he specially selected as most likely to throw light on the volcanic history of the region. He had urged Mr. Arnold-Bemrose to take up with the same

patient and exhaustive industry the field-relations of the rocks. He felt that it would probably be feasible to establish two distinct petrographic types among the dolerites or diabases, one characteristic of the contemporaneous flows, the other of the sills; and that not improbably some distinction might be made out, between the fragmental material which consolidated in the vents, and that which was discharged over the sea-bottom. There were probably many distinct volcanic platforms in the district, but to determine their succession accurately it would be necessary to work out in detail the stratigraphy of the Carboniferous Limestone. Obviously an exceedingly interesting chapter in the volcanic history of this country was recorded in Derbyshire, and he trusted that the Author, living as he did in the county, would undertake to decipher it.

Mr. W. W. Watts congratulated the Author both on the work he had done and on the way in which he had presented it to the Society. He thought that the perfect ophitic structure shown in some of the sections would hardly be developed in a lava-stream, but only in a sill. With regard to the identification of iddingsite, he had found at least two varieties of brown pseudomorphs of olivine in similar rocks, some of which were uniaxial while others were biaxial.

Dr. Johnston-Lavis complimented the Author on working out so thoroughly not only the massive rocks, but also the tuffs, which were frequently neglected. He attributed the absence of olivine either to the circumstance that the mineral has not individualized, or to the facility with which it cracks and breaks up by a change of temperature, so that the fine fragments might be easily overlooked in old altered rocks like these. He would like to know whether the calcareo-igneous breccia was near the bottom of the deposits, as it would most likely occur at the first explosive disruption at the initiation of another cone. At any rate, he should expect it to be associated with pumice, and he thought that one specimen shown by the Author was undoubtedly an old altered pumice.

The Author thanked the speakers for the manner in which they had received the paper. The interesting way in which Sir Archibald Geikie had dealt with the subject would certainly induce him to continue the work. In answer to Mr. Watts, the Peak Forest rock referred to by Sir A. Geikie is an ophitic dolerite. In reply to Dr. Johnston-Lavis, in one place at least, namely, in Ember Lane, the tuff is more calcareous at the bottom of the exposed part of the deposit than at the top. He did not think that the pseudomorph of olivine was a surrounding of olivine by mica, as the alteration proceeded along the cracks until the whole of the olivine was replaced.

40. *On the* Banded Structure *of some* Tertiary Gabbros *in the* Isle *of* Skye.

By Sir Archibald Geikie, D.Sc., LL.D., F.R.S., F.G.S., *and* J. J. H. Teall, Esq., M.A., F.R.S., Sec. G.S. (Read June 6th, 1894.)

[Plates XXVI.–XXVIII.]

Contents.

Introduction.

The dark basic rocks which stand out so prominently in the geological structure and scenery of the Inner Hebrides have long attracted notice and have been the subject of frequent description. The writings of Macculloch,[1] Von Oeynhausen and Von Dechen,[2] and J. D. Forbes[3] in the earlier half of this century, and of Prof. Zirkel[4] and Prof. Judd[5] in the later half, have made geologists familiar with the general character and distribution of the Tertiary gabbros. There is one feature, however, in these interesting masses which has hardly received as yet the attention which it deserves. We refer to the frequent bedding and banding which they present. Even from a distance this structure may be distinctly recognized on many of the great declivities. The northern hills of Rum, for instance, can be readily seen to be built up of successive sheets, and on the flanks of the Cuillin Hills in Skye a similar structure may be observed. Macculloch has referred to what he calls the "obscurely bedded disposition" of some of these rocks, and Prof. Judd has stated that "the great masses of gabbro in Rum exhibit that pseudo-stratification so often observed in igneous rocks." One of the authors of the present paper has drawn particular attention to this structure as evincing that the gabbro masses are not simple eruptive bosses, but are composed of many sills and sheets, the result of successive protrusions of material.[6] He has also dwelt on the fact that not only do these masses exhibit a bedded arrangement of their materials, but that their individual beds sometimes display a

[1] 'Western Islands,' 1819, vol. i.

[2] Karsten's Archiv, vol. i. p. 99.

[3] Edinburgh New Phil. Journ. vol. xl. (1846) p. 85.

[4] 'Geologische Skizzen von der Westküste Schottlands,' Zeitschr. deutsch. geol. Gesellsch. vol. xxiii. (1871).

[5] Quart. Journ. Geol. Soc. vols. xxx. (1874) p. 220; xli. (1885) p. 354; xlii. (1886) p. 49. See also the memoir by A. Geikie in Trans. Roy. Soc. Edin. vol. xxxv. pt. i. (1888) p. 21.

[6] A. Geikie, Trans. Roy. Soc. Edin. vol. xxxv. pt. i. (1888) pp. 124–143.

remarkable arrangement of the component minerals in separate layers, which in their alternation and occasional puckerings recall in a striking way the characters of many ancient gneisses.[1]

We propose on the present occasion to offer a more detailed account than has yet been given of this banded structure among the Tertiary gabbros. The investigation appears to us to have a two-fold interest. In the first place, the structure in question occurs among the deep-seated bosses of the latest volcanic series in Britain. These bosses have undergone no deformation or sensible disturbance since their production. The structures which they present may therefore be accepted as belonging to the original conditions of igneous eruption, and hence a careful study of the nature of this remarkable banded separation of their component minerals may throw some light on the processes concerned in the protrusion and consolidation of igneous magmas.

In the second place, this structure is so closely parallel to that found in some of our oldest gneisses that there can be little doubt that if its nature and origin can be explained, a distinct step will be gained in the interpretation of the history of these ancient rocks.

We shall restrict our description to one locality in Skye—the rugged ridge which strikes from the southern side of Harta Corry and extends between Strath na Creitheach and Coire Riabhach to Loch an Athain. This ridge has no name on the Ordnance six-inch map, and we have been unable to ascertain how it is distinguished by the inhabitants of the district. But the south-eastern part, which is crossed by the tourist footpath to Loch Coruisk, is marked 'Druim an Eidhne' on the map, and to avoid periphrasis we shall include under this appellation the whole ridge up to the crest overlooking Harta Corry.

I. General Arrangement and External Characters of the Rocks.

The ridge which we now describe forms a part of the gabbro mass of the Cuillin Hills. This great region of basic rocks, even if we exclude Blaven and the eastern offshoots, covers an area of some 30 square miles. But as the gabbro can be traced continuously into Blaven, save for the brief interruption of the alluvium of Strath na Creitheach, the total area of this rock is probably not less than 40 square miles. It has been invaded by the granophyre of the Red Hills, which, sending a broad tongue into it as far south as Loch an Athain, separates the Blaven hills from the rest of the Cuillin group. Druim an Eidhne lies on the south-western side of this invading tongue of acid rock. But although in one sense the rocks of this ridge lie at the very edge of the gabbro mass, yet, if we disregard the presence of the younger granophyre, we see that they really belong to the central portion of the gabbro.[2] Hence, in

[1] A. Geikie, *op. cit.* p. 131; Rep. British Assoc. (Nottingham) 1893, pp. 754–755.

[2] The evidence for the younger age of the granophyre has been fully given from the same locality in this Journal, May 1894, vol. l. pp. 212–231.

discussing the various structures presented by the rocks of this locality, we are brought face to face, not with marginal phenomena of protrusion, but with the conditions under which the igneous material was forced upward and consolidated in the deeper parts of a great vent or duct.

No better example could be cited of the remarkably complex nature of the great gabbro areas of the Inner Hebrides than is furnished by Druim an Eidhne. This ridge, though forming part of the central portion of one of these areas, does not consist of merely one type of rock, belonging to one period of extrusion. It is made up mainly of parallel beds, sills, or sheets, disposed in a general N.N.W. direction with a prevalent easterly dip. These, though presenting considerable differences in texture, minute structure, and composition, may be classed under the common designation of 'gabbro.' Along their eastern edge a considerable mass of coarse agglomerate may mark the position of one of the older vents which served as passages for the uprise of the basic eruptive rocks.

Four distinct varieties of material may be recognized among the beds: (1) dark, fine-grained, granulitic gabbros which resemble externally basalt-rocks; (2) well-banded gabbros, composed of irregularly alternating bands and laminæ of the several constituent minerals; (3) coarse massive gabbros destitute of any banding; and (4) pale felspathic veins.

The sequence of these varieties can to a certain extent be definitely established. It was not satisfactorily ascertained whether the first-named series was anterior or posterior to the second. But there can be no doubt that the coarse massive gabbros (3) have sometimes been injected into both of them. It is equally certain that the light-coloured veins are the latest of all, for they traverse all the three other varieties.

1. *The dark, fine-grained Granulitic Gabbros.*—These rocks play a subordinate part in the structure of the ridge. In some parts they weather with a smooth brown surface, on which their minute reticulated veinings of epidote and calcite stand out prominently. Below the outer skin a thin white crust may often be observed. Occasionally small oval patches may be noticed, like half-effaced amygdaloidal kernels.[1] These external features of resemblance to some of the altered conditions of the plateau-lavas are, however, probably deceptive, for, as will be shown, the internal structure of the rocks does not connect them with these lavas.

That these dark fine-grained sheets are older than much of the rest of the gabbro of the ridge is well shown by the way in which the coarser varieties invade them and enclose lenticular patches and blocks of them. But they run parallel with the banded sheets, and though they might be presumed to be older than the latter we were unable to obtain convincing proof of this relation.

[1] Trans. Roy. Soc. Edin. vol. xxxv. pt. i. (1888) p. 169.

2. *The Banded Gabbros.*—It is in these rocks that the chief interest of the series centres. Even from some distance their remarkable structure is recognizable, owing to the striking contrasts of colour which their weathered surfaces present. Parallel strips of pale grey alternate with bars of dark brown, and, as the crags have been intensely glaciated, the structure is revealed as distinctly as if the rocks had been artificially cut and polished. The geologist who is familiar with the aspect of the ice-worn hummocks of Lewisian gneiss in the west of Sutherland, and who for the first time comes upon these bare rocky knolls of Druim an Eidhne, may well be pardoned if he for a moment should be inclined to insist that he has before him another example of the same unmistakable outer features and the same internal structures which characterize the most venerable formation of the north-western Highlands. Nor is this first impression immediately effaced by a closer examination. Not until the whole mass of rock is considered and its relation to the rest of the igneous masses is understood will the idea of an Archæan age be definitely abandoned.

The banded gabbros occur in successive sheets or sills which vary from a few feet to many yards in thickness. Indeed, their upper and lower limits are not easily fixed, except when they are marked by the intercalation of the dark, fine-grained sheets, or where they are truncated by the massive gabbros. Each of these banded sheets consists of many parallel layers of lighter and darker material, which correspond in direction with the trend of the sheet itself, and are usually inclined towards the east or south-east at angles ranging from 20° to 30°. The component layers vary in thickness from mere pasteboard-like laminæ to beds a yard or more in thickness. On a single exposed face of rock they may seem to be as parallel, regular, and continuous as sedimentary deposits. But, as we trace them along the strike, we observe that they are apt to vary in thickness and even to die out. In this general parallelism and discontinuity they present a strong resemblance to the arrangement of the darker and lighter bands among the old banded gneisses.

In yet another particular the analogy with these ancient rocks is sustained by the Tertiary gabbros. The parallelism of the bands sometimes gives way to undulations or puckerings, and even to rapid plications. A remarkable example of this structure is represented in Pl. XXVI., where a group of bands some 10 feet thick has been doubly folded between parallel bands above and below.

Even before a minute examination of the banded structure is made, the observer recognizes it to be due to an aggregation of the several constituent minerals in distinct layers. The paler bands are seen to be those wherein the felspar more especially predominates. The dark brown bands are particularly rich in the ferro-magnesian minerals and magnetite, which project from the weathered surfaces as garnets do from the face of a crag of mica-schist. The thin ribs of glistening black mark where the iron ore is well developed.

A closer inspection reveals the fact that an intimate union exists

between the materials of the successive bands. Instead of being separated by any sharp line of demarcation, they are welded into each other by the mutual penetration of their component minerals. Thus the felspars of the pale bands project among the augites and magnetites of the darker bands, while the latter in turn are enclosed among the felspars.

No trace can be found here of any crushing and re-crystallization, such as are familiar among the schistose rocks. The various minerals, so far as can be judged by the eye, remain in their original condition as they crystallized, save with such alteration as weathering may have effected in them. There are no 'crush-lines' or 'shear-planes,' nor any evidence of mechanical deformation. Even the puckering and plication just referred to is not attended with any sensible effect on the minerals.

In seeking among intrusive sheets of igneous rock for analogies with this banded arrangement, we naturally turn to the familiar forms of what is known as flow-structure. Some of the gabbros of the Inner Hebrides exhibit that structure in the most striking manner. In the mountain Allival in the Island of Rum, for example, there lies near the base of the gabbros a sill of pale troctolite, from 20 to 30 feet thick, in which the felspars are drawn out parallel to the upper and under surfaces of the bed, in such a manner as to impart to the rock a lamination which might cursorily be mistaken for that of some variety of schist.[1] In the banded gabbros of Druim an Eidhne, however, we have not detected any sensible lineation of the individual crystals in the direction of banding. Whatever may have been the conditions under which this banding was produced, they would therefore seem to have differed in some measure from those in which ordinary flow-structure was produced.

The occurrence of banded gabbros has already been described from other regions, and further reference will be made to the observations of previous authors in the second part of this paper. But in these examples derived from rocks of great antiquity there is often the difficulty of determining how far the banding has arisen from some subsequent mechanical movement and re-crystallization. The importance of the instances which we now cite from Skye appears to us to lie in the fact that they undoubtedly reveal original structures.

No great terrestrial disturbances have affected the region since older Tertiary times, when the gabbros of the Western Isles were extruded. We are thus enabled to study the direct results of the protrusion and consolidation of igneous masses unencumbered with any of the doubt and difficulty which often attend the investigation of pre-Cambrian and even of Palæozoic eruptions.

3. *The Coarse Massive Gabbros.*—These rocks, which form the familiar type of gabbro, have their minerals indefinitely aggregated in a granitic texture. They are sometimes exceedingly coarse, with

[1] Trans. Roy. Soc. Edin. vol. xxxv. pt. i. (1888) p. 123.

crystals an inch or more in length. They occur as sheets, veins, and more irregular masses, sometimes traversing and enclosing lenticles of fine-grained granulitic rock or cutting out parts of the banding of the other gabbros. Their posteriority in such cases to the two types of rock already described is thus made quite evident. But where a bed of coarse massive gabbro lies between banded sheets, with no visible evidence of transgression and no traceable connexion with any mass which is transgressive, we are perhaps hardly justified in speaking very positively as to its place in the series of protrusions. All that can be definitely affirmed is that, where the relative sequence of the rocks admits of determination, the coarse massive forms are seen to have been protruded after the first and second groups which have been here described.

4. *The Pale Veins.*—These rocks, from their abundance and their conspicuous whiteness, are prominent features all over Druim an Eidhne, and indeed throughout the region of the Cuillin Hills. They form irregular branching veins from several yards to less than an inch in width, swelling out into thick aggregations and thinning away into mere threads. Their whiteness is so much greater than that of the pale bands in the gabbros, as to show that they contain a large relative proportion of felspar with a smaller amount of augite, olivine, and magnetite. That they belong to the gabbros as part of one complete series of protrusions is recognized in the field, even before the microscope demonstrates their relation to these rocks. Yet they cannot be regarded as mere 'segregation-veins' from the rocks among which they rise. In the first place, the same vein may be observed crossing successively examples of the dark fine-grained sheets, the banded sheets, and the coarse massive gabbro. In the next place, no sensible variation in composition and structure can be detected in these veins, as they strike from a rock rich in felspar to one abounding in magnetite and the ferro-magnesian minerals. They are undoubtedly intrusive where now visible, and, as they cross all the other varieties of gabbro, they must be regarded as marking the latest phase in the gabbro-protrusions of this locality.

II. Microscopical and Chemical Characters of the Rocks.

The Granulitic Gabbros.—In the fresh condition these are dark-coloured, fine-grained, crystalline rocks composed of brown pyroxene, water-clear felspar, green pseudomorphs, and magnetite.

The pyroxene occurs in grains of nearly equal dimensions in the different directions (·1 to ·2 millim.). It is sometimes in the condition of ordinary augite, but more frequently contains the inclusions characteristic of diallage and pseudo-hypersthene.

The grains of felspar resemble those of pyroxene in form and size. Twinning is not uncommon, but the bands are few in number. The extinction-angles point to a variety allied to labradorite. Minute inclusions containing bubbles may be observed with a high power.

The green pseudomorphs agree in form and size with the grains

of pyroxene: they are aggregates of minute prisms or fibres of green hornblende, with which some chlorite is usually associated. The prisms are not, as a rule, orientated in any definite direction, but cross each other in one and the same pseudomorph. Such pseudomorphs are not uncommon in the coarser varieties of gabbro, and they will be referred to in the following description as consisting of pilitic hornblende. The magnetite occurs in smaller individuals than the other constituents and occasionally shows traces of crystalline form.

These rocks are remarkably uniform in composition (sp. gr. 3), and their external resemblance to ordinary basalts has been already referred to. Their typical granulitic structure, the absence of the characteristic lath-shaped sections of felspar, and the frequent occurrence of the diallagic modification of pyroxene are the features which have led us to call them gabbros; but it must be remembered that they are sharply marked off from the rocks which remain to be described by reason of the small size of the individual constituents.

The Banded Gabbros.—These are coarse-grained rocks composed of pyroxene, plagioclase, olivine, and magnetite. Hornblende in three forms, chlorite, and epidote occur as secondary or accessory constituents.

The pyroxene is pale brown in colour, and, so far as our observations go, is in the condition of ordinary augite. The individuals are often elongated in the direction of the vertical axis, and cross-sections occasionally show an approach to the common eight-sided form; but the angles are always rounded. A tendency to ophitic structure is not uncommon. Twinning of the ordinary type may sometimes be observed. Grains of magnetite and pseudomorphs of pilitic hornblende, similar to those already referred to in describing the granulitic gabbros, occur as inclusions. These pseudomorphs may possibly represent olivine. The pyroxene has not unfrequently been partially replaced by uralitic hornblende, and in one case this change was seen to have taken place along cracks which could be followed across the slide for a considerable distance. Where these cracks traversed the augite, the pale brown substance of that mineral was replaced for a short distance on either side by green uralitic hornblende.

Felspar occurs as grains, as irregular ophitic patches, and also in forms which give broad rectangular sections; but these different modes of occurrence are not as a rule found in one and the same specimen. Twinning on the albite, pericline, and Carlsbad plans may be observed. The perfection of crystalline form varies in different rock-specimens. Where the felspar is most abundant (Pl. XXVIII. fig. 1), there the idiomorphism is most pronounced, and where it is least abundant (Pl. XXVIII. fig. 5) it is moulded on the other constituents and shows no trace of crystalline form. The extinction-angles indicate a variety closely allied to labradorite. In a few specimens the felspar has been rendered turbid by alteration, but as a rule it is quite fresh and water-clear.

Unaltered olivine has been recognized only in one specimen taken from a black ultrabasic 'schliere'; and although some of the pseudomorphs of pilitic hornblende may represent this mineral in other specimens, it is probable that it did not play an important part in the original constitution of the rocks. The unaltered substance is nearly colourless in thin section, but the strings of magnetite and the yellow staining along cracks and at the edges of the individual grains, described by Prof. Judd, are well developed. The mineral is not idiomorphic; but the other constituents have been moulded on the rounded grains (Pl. XXVIII. figs. 5 & 6) in such a way as to show that they must frequently be of later date. No inclusions of augite in olivine have been observed.

Magnetite (titano-magnetite) is usually present, either in the form of rounded grains or as large irregular masses. Crystals are rare. The mineral is found also, as we have already pointed out, in the veins traversing the olivines; but this mode of occurrence is quite distinct from that with which we are now more especially concerned. There can be no doubt that magnetite entered largely into the original composition of these rocks. The irregular masses contain rounded grains of augite as inclusions, and these are sometimes so abundant that the magnetite is reduced to the condition of thin strings separating the augite-grains (Pl. XXVIII. fig. 4). The analyses reveal the presence of titanic acid, and on this account polished surfaces of a variety of rock composed of augite and magnetite were etched with hydrochloric acid, in order to ascertain whether the iron ore was an intergrowth of magnetite and ilmenite. No evidence of such intergrowth was obtained. A surface free from cracks appeared to be uniformly attacked, and the solution contained titanic acid.

Brown compact hornblende is very feebly represented in these rocks. It has been observed only in a few specimens, in the form of small irregular patches in the augite. Green hornblende is present, both in the fibrous or uralitic form and in the pilitic form. Secondary hornblende and chlorite not only occur as pseudomorphs, but also in narrow veins traversing the other constituents. The only other mineral which remains to be noticed is epidote. This has been observed only in one or two of the slides; it occurs as irregular grains in the felspar.

The banding which forms so striking a feature of these gabbros is due to a variation in the relative proportions of the four essential constituents — labradorite, augite, olivine, and titano-magnetite. The light-coloured bands are rich in felspar; the dark bands are rich in the ferro-magnesian constituents and magnetite. Here and there black 'schlieren,' composed entirely of augite and iron ore, occur. The more basic portions are not limited to the margins of the masses, but alternate with the more felspathic portions to form the banded complex. There is no essential difference between the different bands as regards coarseness of grain, and the individual minerals interlock with each other across a junction-line just as they do in the central portion of a band. It seems impossible, therefore, to

account for the banding on the supposition that magmas of varying composition have been successively injected. The individual minerals are optically perfect, and their mutual relations are such as occur in igneous rocks. Cataclastic phenomena have not been observed in any of the slides prepared from the banded series, and we therefore conclude that the cause which produced the banding must have operated before the crystallization of the minerals from an igneous magma.

Some idea of the variability in composition of different layers may be formed from the following analyses kindly made for us by Mr. J. Hort Player in the Laboratory of the Survey at the Museum of Practical Geology, Jermyn Street:—

Analysis of	I.	II.	III.
Silica	52·8	40·2	29·5
Titanic acid	·5	4·7	9·2
Alumina	17·8	9·5	3·8
Ferric oxide	1·2	9·7	17·8
Ferrous oxide	4·8	12·2	18·2
Ferric sulphide	......	·4	·4
Oxide of manganese	......	·4	·3
Lime	12·9	13·1	10·0
Magnesia	4·8	8·0	8·7
Soda	3·0	·8	·2
Potash	·5	·2	·1
Loss by ignition	1·2	·5	1·0
	99·5	99·7	99·2
Sp. Gr.	2·91	3·36	3·87

J. Hort Player, April 9th, 1894.

I. (5373 [1]). A light-coloured band mainly composed of labradorite. The other constituents are augite, uralitic hornblende, and magnetite. (See Pl. XXVIII. fig. 1.)

II. (5377). A dark band composed of augite, magnetite, and labradorite. (See Pl. XXVIII. fig. 3.)

III. (5376). A thin ultrabasic 'schliere,' mainly composed of augite and magnetite. (See Pl. XXVIII. fig. 4.)

It is evident from these facts that rock-specimens varying greatly in chemical and mineralogical character may be obtained from the banded gabbros of Druim an Eidhne. Some may be termed normal gabbros, others magnetite-gabbros; while others again consist of magnetite and pyroxene, and may be called magnetite-pyroxenites. These last, however, so far as our observations go, are not developed on any large scale.

Occurrences similar to these are known in many other localities where gabbros, norites, and hyperites are developed on a large scale,

[1] The numbers are those of the microscopic slides in the Collection of the Geological Survey.

especially in Scandinavia and North America.[1] Here, as in most of the other allied cases, the iron ores are titaniferous. The case which comes nearest to the one under consideration is that described by N. H. & H. V. Winchell in Bulletin VI. of the Geological Survey of Minnesota, p. 126. Speaking of the gabbro of the Mesabi Range, the authors say:—"Occasionally a gneissic (laminated) structure is seen in it. Such occurs on the east shore of Birch Lake where a conspicuous hill is marked by parallel weather-lines sloping towards the south, the lines being due to the weathering-out of the contained olivine, which is disseminated in alternating sheets of greater and less prevalence throughout the hill. . . . This gneissic structure is not due to shearing-pressure nor to sedimentation, but to a varying abundance of the more easily decaying minerals, such variation occurring in sheets, and on the weathered edges appearing as depressed lines or grooves." The writings of other authors contain references to gneissic structure in the gabbros and norites which are associated with ore-deposits; and Vogt figures such structures in a dyke of ilmenite-norite at Storgangen in Norway (Geol. Fören. Förh. vol. xiii. 1891, p. 496).

The Coarse-grained Massive Gabbros.—The constituents of these rocks are the same as those of the banded gabbros, except that olivine has not been observed. The uralitization of the augite has often taken place to a greater extent than in the members of the last group, and with the change in the character of the ferro-magnesian constituents is associated a change in the colour of the rocks. The normal gabbros are brown or black; the uralitized gabbros green. The felspars in some of the uralitized gabbros show marked signs of having been fractured and broken; but this action has been local in its character, and may possibly be connected with the molecular changes in the augite. The rocks of this group are much more uniform in composition than those of the banded series. Nevertheless variations in the relative proportions of the different constituents do occur. The specific gravities of three specimens are respectively 2·82, 2·97, and 3·06.

The later Gabbro-veins.—These rocks are composed of the same constituents as those of the last group; but the felspar is, as a rule, far more abundant, so that they are lighter in colour. Inclusions of the fine-grained granulitic gabbro occur in the veins. Apatite, which has not been noticed in the rocks of the other groups, is easily recognizable in the veins. In the few specimens from which microscopic sections have been prepared hornblende predominates

[1] See A. Sjögren (Geol. Fören. Förh. vol. iii. p. 42, 1876, and vol. vi. p. 264, 1882); Törnebohm (*ibid.* vol. v. p. 610, 1881); Vogt (*ibid.* vol. xiii. 1891); Wadsworth (Lithological Studies, Mem. Mus. Comp. Zool. Harvard, vol. xi. 1884); Winchell (Minnesota Geol. Surv. Bull. vi. 1891); Adams ('Ueber das Norian oder Ober-Laurentian,' Neues Jahrbuch, Beilage-Band viii. 1893). An ore-deposit, consisting of magnetite and pyroxene associated with a peculiar nepheline-pyroxene rock (jacupirangite), has been described by O. A. Derby, Amer. Journ. Sci. ser. 3, vol. xli. (1891) p. 311.

over the augite, and assumes in some cases a more compact character than is the case in the other rocks. Taking the rocks of Druim an Eidhne as a whole, the compact hornblende which forms so marked a feature in the foliated gabbros of the Lizard is conspicuous by its absence, and so also is the saussuritic modification of the felspar. The specific gravities of two specimens from the veins were found to be 2·78 and 2·85 respectively.

III. General Deductions.

From the facts which have been here described we may proceed to indicate some of the conclusions which seem to us to be legitimately deducible from them. There are two lines of enquiry on which these facts may be made to throw some light. In the first place we may enquire how far they serve to extend our knowledge of the conditions under which igneous magmas may be protruded and consolidated, and in the second place we may consider to what extent the phenomena exhibited by these Tertiary gabbros serve to elucidate the structure and origin of the oldest gneisses.

(i) We are accustomed to think of an igneous magma as fairly uniform in its composition at the time of its intrusion into surrounding rocks or extrusion at the surface; and in the majority of cases this view is probably correct, so far as the massive igneous rocks are concerned. If samples equal in bulk to that of an average hand-specimen could be taken from various portions of the molten mass at the time of its rise to the place where the igneous rock is now observed, they would probably be found to possess the same, or very nearly the same, chemical composition. Crystals are no doubt often present in the magma at the time of its intrusion or extrusion, but they are usually distributed with approximate uniformity through the still molten material, and do not, therefore, affect the question we are now considering. As an illustration of uniformity in the composition of one and the same mass of rock we may refer to the Cleveland Dyke, which has been traced at intervals for a distance of 90 miles across the North of England. It traverses Jurassic, Triassic, and Carboniferous strata of the most diverse petrographical characters without undergoing any marked change either in composition or structure.[1]

Turning now to larger masses of rock which occur as sills, laccolites, and bosses, we find that uniformity in composition is not so marked a feature as it is in the majority of dykes.[2] Such differences as occur may, however, in many cases be explained by differentiation subsequent to intrusion—differentiation *in situ* as it may be termed—

[1] 'Petrological Notes on some North-of-England Dykes,' by J. J. H. Teall, Quart. Journ. Geol. Soc. vol. xl. (1884) p. 209.

[2] But dykes are not always uniform in composition. See A. Geikie, 'The Pitchstone of Eskdale,' Proc. Roy. Phys. Soc. Edin. vol. v. (1880) p. 219; A. C. Lawson, 'Petrographical Differentiation of certain Dykes of the Rainy Lake Region,' 'American Geologist,' vol. vii. (1891) p. 153; Prof. J. W. Judd, 'On Composite Dykes in Arran,' Quart. Journ. Geol. Soc. vol. xlix. (1893) p. 536.

mass during intrusion that the banded structures were produced. This is our hypothesis. We do not offer it as an original one, but merely as that to which we have been led from a consideration of the facts above described.

(ii) We pass on now to consider the extent to which the phenomena exhibited by these Tertiary gabbros may serve to elucidate the structure and origin of some of our oldest gneisses. The extraordinary resemblance of these gabbros to the Norian (anorthosite) rocks of the North American Continent was clearly recognized by earlier observers. More detailed observation has served to extend the points of resemblance. The deposits of titaniferous iron ore and the gneissose structures of the Norian formation have their analogues in the black masses, extremely rich in titano-magnetite, and in the banded structures to which attention has been directed in this paper. It seems impossible, therefore, to avoid the conclusion that the cause, whatever it may have been, which produced the phenomena in the one case operated in the other, and that the pre-Cambrian anorthosite rocks of Canada originated under physical conditions closely allied to, if not identical with, those which give rise to the Tertiary gabbros of Skye.

It will be interesting, however, to compare these gabbros with Archæan rocks nearer home. The Lewisian gneiss of the North-west of Scotland is a petrographical complex, largely but not entirely composed of gneisses having marked affinities with plutonic igneous rocks. The area of this ancient formation already mapped in detail by the Geological Survey forms a narrow border along the coast, extending from Cape Wrath to Loch Torridon. In no portion of this area do rocks of uniform character cover any large tract of country, but extreme petrographical diversity may be said to characterize the formation. Between Cape Wrath and Loch Laxford hornblendic and micaceous gneisses predominate, and these are often traversed by intrusive veins and sills of gneissose granite and pegmatite. The area south of this district, extending from Scourie to some distance beyond Loch Inver, is very largely composed of augitic gneisses, with which banded rocks of ultrabasic composition —peridotites, pyroxenites, and pyroxene-granulites—are associated. Hornblendic and micaceous gneisses also occur. Another feature of this area is the extraordinary abundance of basic dykes. Southwards, in the neighbourhood of Gairloch and Loch Torridon, hornblendic and micaceous gneisses again predominate, and bands of hornblende-schist, which appear to represent the dykes of what we may refer to as the middle zone, are extremely numerous. In the neighbourhood of Loch Maree limestone, garnetiferous mica-schists, and graphite-schists occur. As these are probably metamorphosed sediments, we need not further refer to them in the present communication.

The petrographical changes are sometimes gradual and sometimes abrupt. The mode of association of the different varieties, or the architecture of the rock-masses, as Prof. Brögger would say, is

extremely diversified. In some places no definite order of arrangement can be made out; in others we find veins of more acid material penetrating masses of more basic material: and in others a kind of breccia has been formed, in which lumps and fragments of basic rocks lie in a matrix of acid rocks. Then, again, every possible kind of parallel structure may be observed. In some cases this is only faintly indicated in the arrangement of the minerals, or in the forms and mutual relations of the more or less differentiated masses, and from this condition every intermediate phase may be followed to the most perfect parallel banding. Many causes have doubtless operated in the production of the results which we now see, and much work will have to be done before all these causes are clearly recognized, and the effects of each accurately defined. One great difficulty, with which the geologist has to contend in his attempt to unravel the complicated story of the Lewisian gneiss, is that of separating the effects due to causes operating before or during the consolidation of igneous magmas from those due to dynamic action operating upon the rocks after consolidation.

In the middle area—that is, in the district between Scourie and Loch Inver, where innumerable basic and a few ultrabasic dykes clearly cut the fundamental gneiss—the existence of narrow belts of country, 'shear-zones,' as they have been termed, along which the rocks have been affected by secondary dynamic action, can be clearly demonstrated. Along these zones the granitic gneiss often becomes granulitic, hornblende takes the place of augite, and quartz-veins often make their appearance. The dolerite-dykes, where they abut against the shear-zone, which is often also a line of fault, tail off into hornblende-schist, and the ultrabasic dykes (in some cases at least) into talc-gedrite-siderite-schist. Between these zones we find areas which have certainly not suffered deformation since the dykes were formed, and it is precisely in such areas that structures most nearly allied to those of the banded gabbros are to be found.

The ultrabasic portions of Lewisian gneiss about Scourie and Drumbeg may be especially referred to in this connexion, although probably much of the banding in other localities and affecting other kinds of rocks is of the same nature and origin. The separation of the component minerals of these varieties of gneiss into definite parallel bands presents so remarkable a resemblance to the structure which we have described from the Tertiary basic rocks of Skye, that it is difficult to believe that they cannot have arisen from the same conditions.

Geologists now generally agree in regarding the older gneisses as mainly rocks of igneous origin. And this view, as it seems to us, is strengthened by the detection of so close an analogy between the banding of these rocks and that of basic eruptive bosses. There seems to be good reason to believe that this structure in the undisturbed igneous rocks is not a mere local accident, but that it occurs, as at least an occasional phenomenon, among basic eruptions of many different ages from Archæan to Tertiary time.

We suspect that much of the banding among the old gneisses, as

ruim an Eidhne, Skye, 10 feet broad.

Granulitic and Foliated Gabbro tra

distinguished from mere foliation, which has been ascribed to late mechanical deformation, may be an original structure due to the conditions in which the igneous magma was erupted and consolidated. In view, however, of the undoubted evidence of secondary dynamic action in many regions, and in the absence at present of any well-established criteria by which we can in all cases discriminate between original and secondary structures, we are not yet in a position to define the exact limits within which the hypothesis of the intrusion of heterogeneous magmas is applicable to the explanation of the structures of the Lewisian gneiss.

EXPLANATION OF PLATES XXVI.-XXVIII.

Plate XXVI.

Folded and Banded Gabbros at Druim an Eidhne, 10 feet broad.

Plate XXVII.

Granulitic and foliated gabbro, traversed by later veins of felspathic gabbro, at Druim an Eidhne. The irregular white patches are the relics of veins of felspathic gabbro.

Plate XXVIII.

Fig. 1 (5373 in Surv. Collect.). From one of the light-coloured felspathic bands. The minerals represented are plagioclase, uralitic hornblende, and magnetite.

Fig. 2 (5377). From one of the dark bands rich in augite and magnetite. The minerals present are plagioclase, augite, and magnetite. Some of the augite-grains occur as inclusions in the interstitial magnetite.

Fig. 3 (5375). From a band of intermediate character. The minerals represented are plagioclase, uralitic hornblende (scarce), and iron ore. The portion of the slide selected for representation is exceptionally rich in magnetite, which is seen to fill up the spaces between the felspars.

Fig. 4 (5376). From one of the black ultrabasic 'schlieren.' The only two minerals present in the portion represented in this figure are augite and magnetite.

Fig. 5 (5374). From one of the black ultrabasic 'schlieren.' Composed of olivine, felspar, and magnetite. The magnetite occurs in veins traversing the olivine, and also as grains independent of that mineral. The plagioclase, which occupies the centre of the figure and fills up the irregular space between the other minerals, belongs to one crystalline individual.

Fig. 6 (5374). Another portion of the same slide. The minerals here represented are olivine, augite, and magnetite.

Discussion.

Dr. Johnston-Lavis wished to know if there was any special orientation of the crystals in the different bands, and also whether the thinner bands were the more basic, as these facts would help to elucidate their origin. He quite agreed with the Authors that the differentiation of the magma was anterior to its taking up its present position. He remarked that frequently effusive rocks showed a banding of this nature due to differential shearing between portions of the magma of different viscosity, and such might be the

case also in injected rocks: hence the reason of the questions that he had put.

Prof. Blake remarked that one of the Authors, after paying a visit to Anglesey, had described the general aspect and structure of certain gneiss-like rocks in almost identical terms with those now used for the gabbros of Skye, which the Authors regarded as Tertiary; yet, on the ground of such aspect and structure, the Anglesey rocks were considered to be of the age of the Hebridean gneisses. He hoped that it would now be admitted that the age of rocks could not by these particulars alone be determined.

Dr. Hicks said that the facts stated by the Authors were very interesting, as bearing on the possible cause of the banded structure in some of the Lewisian gneisses. It was now generally admitted that the more massive of the pre-Cambrian gneisses must have had an igneous origin; but the mode by which the banding had taken place remained somewhat doubtful.

The point raised by Prof. Blake was easily disposed of, as it was seldom necessary to rely upon petrological characters only; and in the case of the Anglesey gneisses there was good stratigraphical evidence to show that they were of pre-Cambrian age.

Mr. Harker found the paper of much interest from a purely petrographical point of view, as well as for its bearing on the origin of ancient gneisses. Banded structures are well known in many basic plutonic masses, but the examples described in this paper are more striking than any hitherto recorded.

Mr. J. Hort Player also spoke.

Sir Archibald Geikie stated in reply that, so far as he knew, no relation was observable between the breadth of the bands in the gabbro and their basicity, nor at the locality referred to in the paper was there any marked orientation of the crystals parallel to the planes of banding. Among some of the basic sills of the Western Isles, however, such orientation was strongly developed, and he particularly cited a troctolite sheet in the Island of Rum, in which the laminar arrangement was so conspicuous that the rock might at first be mistaken for a schist. The observations recorded in the paper did not seem to him to have any bearing on the age of the rocks in the centre of Anglesey, referred to by Mr. Blake, regarding which his opinion remained unchanged.

41. Additions *to the* Fauna *of the* Olenellus-zone *of the* North-west Highlands.

By B. N. Peach, Esq., F.R.S., F.G.S., of the Geological Survey of Scotland. (Communicated by permission of the Director-General of the Geological Survey. Read June 20th, 1894.)

[Plates XXIX.–XXXII.]

Contents.

I. Introduction.

It is now two years since Mr. Horne and I communicated to this Society details of the discovery by the Geological Survey of *Olenellus* in the 'Fucoid Beds' and Serpulite Grit of the west of Ross-shire, which in our opinion proved the Lower Cambrian age of those strata. The discovery has been followed up by the Survey, and through the kindness of Major Robertson, the shooting tenant, and of Mr. A. P. Purves, the agent for Mr. Mackenzie, the proprietor of the Dundonnell Forest, facilities were afforded to Mr. A. Macconochie, Fossil Collector of the Survey, which allowed him to make a more exhaustive search of the localities mentioned in our paper. The search resulted in his obtaining a considerable amount of new material.

While the work of the Survey was advancing in the region around the head of Loch Maree, prior to the discovery of *Olenellus* at Dundonnell, certain outcrops of the 'Fucoid Beds' were considered fossiliferous, and were accordingly marked off to be further searched by the collector. One of these, situated in Glen Cruchallie, more commonly, though erroneously, known as Glen Logan, yielded Mr. Macconochie specimens of *Salterella* and *Hyolithes*, but no recognizable fragments of trilobite. The other outcrop, noticed by Mr. Greenly, occurs on the northern slopes of Meall a' Ghubhais at a height of between 1200 and 1300 feet, just over the tree-line, and about 4 miles north-west of Kenlochewe. As this locality is situated in the Sanctuary, or most carefully preserved part of the Kenlochewe Deer Forest, it could not be searched when Mr. Macconochie's services were available, owing to the approach of the stalking season.

Early in the field-work of last year, Messrs. Horne, Gunn, and Clough had occasion to visit this locality, in order to study the effects of movement on different members of the Torridonian Series, which have there been thrust over the Cambrian rocks and left as an outlier by denudation to form the upper part of Meall a' Ghubhais.

At the same time, they made a short search at this exposure of the 'Fucoid Beds,' which, although they lie not far beneath the outcrop of the 'thrust-plane,' are comparatively free from disturbance. Mr. Horne found a fine specimen of *Acrothele subsidua*, a small brachiopod which is associated with the *Olenellus*-fauna in Utah and Nevada. Mr. Macconochie was soon afterwards despatched to Kenlochewe, and having had every facility afforded him by Mr. Cazalet, the tenant of the forest, soon struck upon the beds which yield *Olenellus*, and made a fine collection. He likewise returned to the outcrops in Glen Logan and proved the occurrence of *Olenellus* in the 'Fucoid' Shales there; but, in consequence of the strata being much affected by post-Cambrian movements, the specimens are too indistinct for description. The collections thus secured were placed in my hands, as acting Palæontologist to the Geological Survey of Scotland, and, by permission of the Director-General, I now beg to lay before this Society as a sequel to the former paper [1] a description of the trilobite-remains.

II. Description of a new Sub-genus and some new Species of Trilobites.

The trilobite-remains in this collection consist of several hundred fragments, chiefly head-shields, a few nearly complete individuals with both head-shields and body-segments attached, several minor fragments affording good material for study, and a large number of pieces that may be called scraps. These various specimens enable me to complete the account of the structure of *Olenellus Lapworthi*, described by me from head-shields alone, as well as to announce the existence of other species of the genus. Moreover, the specimens include numerous head-shields and one almost complete individual that appears to belong to a separate sub-genus.

Genus Olenellus, Hall.[2]

Olenellus Lapworthi, Peach. (Pl. XXIX. figs. 1, 2, 2 *a*; Pl. XXX. fig. 7.)

Head-shield described in a former paper.[3] Body-segments, fourteen in number, all free, with well-embossed axes divided from the pleura by shallow axal furrows, and each bearing in the mid-line near the posterior margin a small tubercle or short spine. The pleura, which are wide, with thickened fulcral margins, well-marked fulcral grooves, and thickened posterior margins, are bent back suddenly upon themselves opposite the end of the fulcral groove, and terminate in a more or less produced, recurved spine. The axes, which, next to the head-shield, are nearly as wide as the occipital ring itself, carry their breadth down to the third segment; thence they diminish backward till the axis of the fourteenth segment is a little less than one half the breadth of the first.

[1] Quart. Journ. Geol. Soc. vol. xlviii. (1892) pp. 227–241.
[2] The genus *Olenellus* is here used in the restricted sense explained in my former paper, *op. cit.*
[3] *Ibid.*

The relation of depth to breadth is nearly the same in all the axes, and varies in the proportion of 1 : 3 or 3 : 8. The pleura, in consequence of overlapping each other, are a little deeper than the corresponding axal portions. Those of segment No. 1 are directed slightly forward, and preserve their full breadth as far as the pleural angles of the head-shield, where they are abruptly truncated, their postero-lateral angles being each set with a short spine. In segment No. 2 the pleura are set at right angles to the general axis of the body, and extend to the tips of No. 1; but they are not so sharply truncated as in that segment, being bent back and ending in rather longer spines.

The pleura of segment No. 3 form a most conspicuous feature. They gradually expand from the axis outward till they attain double its breadth opposite the pleural spines of the preceding segment, beyond which they suddenly bend off at almost right angles, taper rapidly, and are continued into more or less flattened spines nearly as long as the pleura themselves. The fulcral ridges and grooves are also more pronounced on this segment than on any other.

In consequence of the great expansion of the pleura of segment No. 3, those of No. 4 are directed slightly backward. They are much narrower and shorter than the pleura of the former segment, their fulcral points being well within its posterior curves. Like those of No. 1, they terminate abruptly, but their spines are a little longer than in that segment. In No. 5 the pleura are set more distinctly backward, and are a little longer in proportion to the size of the axis than those of No. 4; their terminal spines also are somewhat longer.

In segment No. 6 there is a sudden increase in the size of the pleura, especially in the spines, that reminds one of No. 3. The succeeding four segments are all much like No. 6 in appearance, though the pleura of each are set at a smaller angle to the axis than the immediately preceding ones, and the spines are each in turn more bent inward towards their tips in order to prevent overlapping.

The hindermost four segments have their pleura set at an increasingly acute angle to the axis, till the posterior margins of those of the fourteenth segment almost coincide in direction with it, while their spines rapidly and successively become smaller.

The telson has not been observed in place, but it is presumed that it is styliform, precisely as in the variety of this species which will be subsequently described. The whole of the parts are more or less marked by the peculiar reticulated pattern described in my former paper (*op. cit.* p. 239, pl. v. fig. 2 *b*). This sculpture is most conspicuous on the glabella and cheeks, and on the anterior portion of the axes and the pleura of the body-segments. In this species it is small, compared with the size of the animal.

The chief character which distinguishes *Olenellus Lapworthi* from

all the American species as yet described is that the posterior angles of the eye-lobes are set much farther out from the edge of the glabella in this species—a character which it shares in common with all the other species in the collection under review. From *Olenellus Thompsoni* and *O. Gilberti*, which it most nearly approaches, it is further distinguished by the line of tubercles ranging from the occiput, and extending down the axes of all the segments.

TABLE OF MEASUREMENTS OF *Olenellus Lapworthi*.

	M. 4085[d]. Pl. XXIX. fig. 1.	M. 4078[d]. Pl. XXIX. figs. 2 & 2*a*.
	mm.	mm.
Length of head-shield and first ten segments of body	25	
Length of head-shield and body-segments, exclusive of telson ...	....	20
Length of head-shield	13	9
Breadth of do.	26	20

The figures at the top of the columns are the registered numbers of the specimens in the books of the Geological Survey of Scotland.

OLENELLUS LAPWORTHI, var. ELONGATUS, nov. (Pl. XXIX. figs. 3–6.)

This name is proposed to include the more elongated forms of this species. Fig. 3, Pl. XXIX., represents a nearly complete specimen enlarged two diameters. In general contour of the body, it is somewhat more elongated than *O. Lapworthi*. Its specially distinguishing feature, however, is the unusually developed pleural spines of the third body-segment, which not only extend much farther backward than in that species, but are curved inward in the same manner as in *Olenellus Gilberti*, a species found on the side of the Rocky Mountains opposite to that wherein *O. Thompsoni* has been found. Like the former, it appears to have terminated in a long spear-like telson, portion of which is seen in fig. 3, Pl. XXIX., which is too imperfect to show the details of its configuration or to indicate its probable length.

Several fragments of the third body-segment of this form are preserved in the collection under review. The test of this variety is ornamented with a sculpturing similar to that of *O. Lapworthi*. A portion of a labrum which seems to belong to this variety is reproduced in Pl. XXIX. fig. 5, magnified two diameters.

The specimen from which fig. 3, Pl. XXIX., was taken gives the following measurements :—

Full length without telson	22 mm.
,, with ,, ...	25 ,,
Length of carapace	10 ,,
Breadth of do.	19 ,,
,, body across third segment ...	14 ,,

Olenellus reticulatus, sp. nov. (Pl. XXX. figs. 1–6, 8–14; Pl. XXXI. figs. 1–7.)

In the collection under review there are numerous remains of an *Olenellus* of much larger size than *O. Lapworthi*, which in many other respects it greatly resembles. The reticulated ornament on its test appears to be much larger in pattern (compared with its size) than in that species, and this difference, which makes it conspicuously visible to the naked eye, has suggested the specific name which I propose for the new form. In general aspect it much resembles the elongated variety of *O. Lapworthi*. It differs from that chiefly in the head-shield, which is deeper in comparison with its breadth. The glabella is longer in proportion to the size of the head-shield, and the individual lobes are each more elongated, while the angles made by the furrows with the general axis of the body are more acute. The distal ends of the eye-lobes are not so far removed from the edge of the glabella, nor do they extend so far backwards, but end well in front of the fourth furrow, while those of *O. Lapworthi* extend beyond it. The raised margin that bounds the cheeks is not so wide in proportion; the genal spine is more slender, and is placed a little more anteriorly, and the notch between it and the pleural angle is deeper than in *O. Lapworthi*.

The arrangement of the details of its body-segments is similar to that of *O. Lapworthi*, but the peculiarities of the pleura of the third segment are even more pronounced, the spines being longer relatively, and sometimes more incurved. The spines on the pleura of the sixth and three succeeding segments are longer and more slender. Tubercles have been observed in the mid-line on the occipital ring, on the axes of the first three free segments, and on several of the posterior ones. They have not been observed on all the intermediate segments, but this may be owing to bad preservation or faulty observation, as it is probable that they once existed.

The telson is long and styliform, and tapers rapidly at first and then decreasingly. Its articulation with the last free segment is well shown in the specimen from which Pl. XXX. fig. 12 was taken. Projecting from the posterior margin of the axis of the fourteenth free segment, at about $\frac{1}{5}$ of its width from each side, are two small protuberances. Corresponding projections proceed forwards from the hinge-line of the telson, and interlock with them on their outside. Beyond them the anterior edge of the telson is continued in nearly the same line with the hinge, so that the anterior angles of the telson appear to be overlapped by the pleura of the last free segment. A 'lock joint' is thus formed which does not allow of the telson folding downward beyond a certain angle with the plane of the last segment.

A detached labrum which may have belonged to an individual of this species is shown, nat. size, in Pl. XXX. fig. 13.

There appears to be a considerable range in the configuration of different individuals of this species. Pl. XXXI. fig. 3 represents an elongated form which appears to have been even further elongated, and in fact distorted after having been embedded in the rock.

Pl. XXXI. figs. 1 and 2 show what appears to be a broader form, but it has been distorted first by having the first two free segments 'telescoped' into the head-shield, and by having the body folded upon itself at the eighth free segment, the dorsal tubercle of which is well seen against the matrix at the fold. By a fortunate breaking-away of part of the test which adheres to the counterpart, the pleura of the hindermost segments and the greater portion of the telson can be observed at a lower level in the matrix. Since it has been embedded, the specimen has been further broadened and distorted by faulting of the matrix.

TABLE OF MEASUREMENTS OF *Olenellus reticulatus*.

	M. 4076^{d}. Pl. XXX. fig. 1.	M. 4104^{d}. Pl. XXX. fig. 2.	M. 4161^{d}. Pl. XXX. fig. 4.	M. 4142^{d}. Pl. XXXI. figs. 1, 2.	M. 4078^{d}. Pl. XXXI. g. 3.	M. 4093^{a}. Pl. XXX. fig. 5.
	mm.	mm.	mm.	mm.	mm.	mm.
Full length of parts preserved	......	......	50			
Length of head-shield ...	29	33	......	......	......	27
Breadth of do. ...	50	46	60	50	......	40
Length of body	......	......	40	......	27	
,, eight segments	......	......	......	33		
Breadth of third segment	......	......	40	36	24	
Length of spine of do....	......	......	22	20	20	
Length of telson visible...	......	......	......	15		

OLENELLUS GIGAS, sp. nov. (fig. 1, p. 667).

Fragments of a large species of trilobite with a strong genal spine and reticulated ornament were figured in a former paper (*op. jam cit.* pl. v. figs. 12, 12 *a*, 12 *b*). In the present collection a specimen occurs which gives most of the detail of the dorsal aspect of the head-shield: this is much wider compared with its depth than in *O. Lapworthi* and *O. reticulatus*. It is further distinguished from the latter by its broad margin and strong genal spine. The ornamentation is readily seen, even with the unaided eye. As stated in the former paper, the pattern of the reticulation is more elongated on the margins and spines than on the general surface, but this applies equally to all the species of *Olenellus*.

Portions of cheeks and genal spines of individuals nearly as large as the above, on which the pattern of the ornamentation is much smaller proportionally to their size, occur in the collection.

Measurements of carapace of *Olenellus gigas*, M. 1154^{d}:—

Length of head-shield .... 52 mm.
Breadth of do. .... 106 mm. = $4\frac{1}{4}$ inches.

OLENELLUS INTERMEDIUS, sp. nov. (Pl. XXXII. fig. 7.)

This species is founded on a single head-shield, preserved in relief in a decomposing ochreous bed, and its counterpart. It is doubtfully

margin to the posterior margin, is rounded in front, broadest at the base of the eye-lobes, and narrowest to just behind the second furrow. It then increases in breadth backward. It is divided into five lobes by furrows which are not so much bent backward in the middle as in *O. Lapworthi*. A small tubercle occurs on the occipital ring. The eye-lobes are reniform, and set out at more obtuse angles than in any of those already described; they extend back only so far as to be opposite to the second glabellar furrow. The area in the angle made by the glabella with the eye-lobes is tumid. The test is ornamented with the characteristic reticulate pattern.

Measurements:—

Length of head-shield	....	3 mm.
Breadth of do.	....	7·5 „
Length of genal spine	....	2·5 „

OLENELLOIDES, subgen. nov.

The collection of fossils from Meall a' Ghubhais contains numerous head-shields, and one specimen and its counterpart with head-shield and eight body-segments attached, of a peculiar, small, narrow trilobite armed with long spines at regular intervals. It is evident that it is nearly allied to *Olenellus*, in which genus I should prefer to allow it to remain; but though all the specimens may belong to only one species, yet the individuality of that species is so strongly marked that perhaps it would be better to place it in a separate sub-genus taking rank with *Holmia* and *Mesonacis* under *Olenellus*. The name that I have proposed for it is intended to show its strong likeness to some larval stages of other Olenellids.

Description. Small, elongated, and narrow in general outline, and set with long spines at regular intervals.

Head-shield roughly hexagonal, produced into long and strong spines at all the angles, and strengthened on all sides except the posterior one by a strong, rounded, raised margin, which is widest at the angles. Its greatest width is across from base to base of the mid-pair of marginal spines. The glabella, which occupies about half the area of the head-shield, is well embossed, almost cylindrical, divided into five distinct lobes, and extends nearly the whole length of the shield. It is rounded in front, slightly constricted near the second furrow, and widest at the occipital ring, which bears a small blunt tubercle in the mid-line. The eye-lobes are reniform, proceeding out from the frontal lobe just in front of the first furrow, and with their distal ends well set out from the glabella. The visual slits occupy nearly the whole length of the outward or convex edges of the eye-lobes. No free cheeks nor facial suture.

Number of body-segments unknown. The characters of the eight preserved show that the body was long and narrow, and that the segments are well trilobed, with highly embossed axes, which are wide compared with the pleura. The latter are marked off from the axal parts by a shallow furrow, have fulcral thickening in front, wide fulcral grooves, and end in short spines at the postero-lateral angles, except in the third and sixth segments, where the spines are

long and strong. The body suddenly narrows behind the sixth segment, and the pleura of the seventh and eighth segments are very small; hence it is inferred that it would require only a very few more segments to complete the body. Nature of telson unknown.

The characteristic features of this sub-genus are the great size of the axis of the body compared with the cheeks and pleura, the hexagonal head-shield with its angles set with spines, and the recurrence of larger pleura and highly elongated spines on the third and sixth body-segments.

Olenelloides armatus, sp. nov. (Pl. XXXII. figs. 1–6.)

The head-shield, which is hexagonal and set with long spines at the angles, is of about the same length as the first six body-segments and varies in proportion in different individuals as 1 : 1 and 4 : 3. It is bordered on five sides by a thickened, rounded margin, which is widest at the angles. The anterior margin between the first pair of spines is convex, and these spines are set forward at angles of about 30° to 35° to the general axis of the body. The margins between these and the lateral spines make almost straight lines, the head-shield being at its widest opposite the bases of these lateral spines, which are set backward at angles of about 50° to the axis of the body. Behind these spines the shield tapers rapidly at first and then more gradually, so that the margins between the lateral spines and the posterior ones are concave. The posterior spines are directed backward and set at an angle of about 30° to the long axis of the body; they are slightly curved inward towards their tips.

The posterior margin is convex, being made up of the posterior margin of the occiput, which constitutes $\frac{3}{5}$ of the whole, the remaining $\frac{2}{5}$ being occupied by the margins of the cheeks, which are marked off from the occipital part by deep notches. The glabella, which is nearly cylindrical and rounded in front, extends almost from end to end of the head-shield, and occupies the greater part of the cephalic area. It is divided into five lobes, wide in front, narrowing somewhat at the lobe behind the first furrow, and widest at the occiput. The furrows are nearly M-shaped, in consequence of which the frontal lobe is pear-shaped and the others are more or less cordate, the lobe immediately behind the first furrow being the smallest. The occipital lobe bears a small spine or tubercle in the mid-line. The eye-lobes are reniform, proceed out from the frontal lobe towards the outer margin, and terminate just behind the bases of the lateral spines opposite the third lobe of the axis, the ocular slit extending throughout the greater part of its outer or convex margin. The cheeks in front of the eye-lobes and glabella are hollow. A narrow ridge runs from the angle made by the eye-lobe and the glabella as far back as to opposite the third furrow; another ridge runs from this furrow to the base of the posterior spine. These ridges are separated from the glabella and eye-lobes by deep furrows. No free cheeks nor facial suture observed.

Body-segments, number unknown, eight only being preserved.

Each of these consists of a well-marked axis, very large in proportion to the pleura, from which it is marked off by shallow axal grooves, and bearing a tubercle or small spine in the mid-line near the posterior edge. The axis of the first segment is of about the same width as the occiput, and this width is maintained as far as that of the third segment. From this point they taper gradually backward to the sixth segment, behind which there is a comparatively sudden contraction, the seventh and eighth segments being much smaller than any of the rest. The pleura, which are almost quadrate in shape, have fulcral ridges and grooves, and spines on their postero-lateral angles. These are small and insignificant, except on the pleura of the third and sixth segments, which are long and strong, and set backward at almost the same angle as the posterior spines of the head-shield.

From the sudden tapering behind the sixth segment, and from the nature of the pleura of the seventh and eighth segments, which are especially small and set backward, it is inferred that the body never bore many more than those exhibited. The nature of the terminal segment or telson is unknown, though it was in all probability styliform.

Some of the specimens show that the test was ornamented with a reticulated pattern, as in *Olenellus* and other early trilobites.

TABLE OF MEASUREMENTS OF *Olenelloides armatus*.

	M. 4111d. Pl. XXXII. figs. 1–3.	M. 4116d. Pl. XXXII. fig. 4.	M. 4117d. Pl. XXXII. fig. 5.	M. 4127d. Pl. XXXII. fig. 6.
	mm.	mm.	mm.	mm.
Length of head-shield and eight segments, exclusive of spines	11			
Length of head-shield, exclusive of spines	5	4·75	3	4
Breadth of do.	4	4·5	2·5	4
Breadth at anterior margin	2	3	1·75	2·5
,, ,, posterior do.	3	3·5	1·75	3
Average length of spines on head-shield	2·5	2·5	2·5	
Average breadth of axis of glabella	1·75	1·75	1·25	1·75
Breadth of 1st body-segment	3·5			
,, of axis of do.	1·75			
Depth of do.	1			
Breadth of third segment	3·75			
,, of axis of do.	1·75			
Depth of do.	1			
Length of spine on do.	2·25			
Breadth of sixth segment	2			
,, of axis of do.	1			
Depth of do.	·75			
Length of spine on do.	1·5			
Breadth of seventh and eighth segments	1			
Depth of axis of do.	·4			

Genus Bathynotus, Hall.

Bathynotus holopygia? Hall.

Some fragments consisting of a portion of a glabella and fixed cheeks, and several slender spines of trilobites which cannot well belong to any known species of *Olenellus*, but which fairly answer to the description of parts belonging to *Bathynotus holopygia*, occur in the collection under review, and have been provisionally named as above till such time as further evidence regarding their nature is forthcoming.

III. Theoretical Considerations based upon the Study of the Remains described.

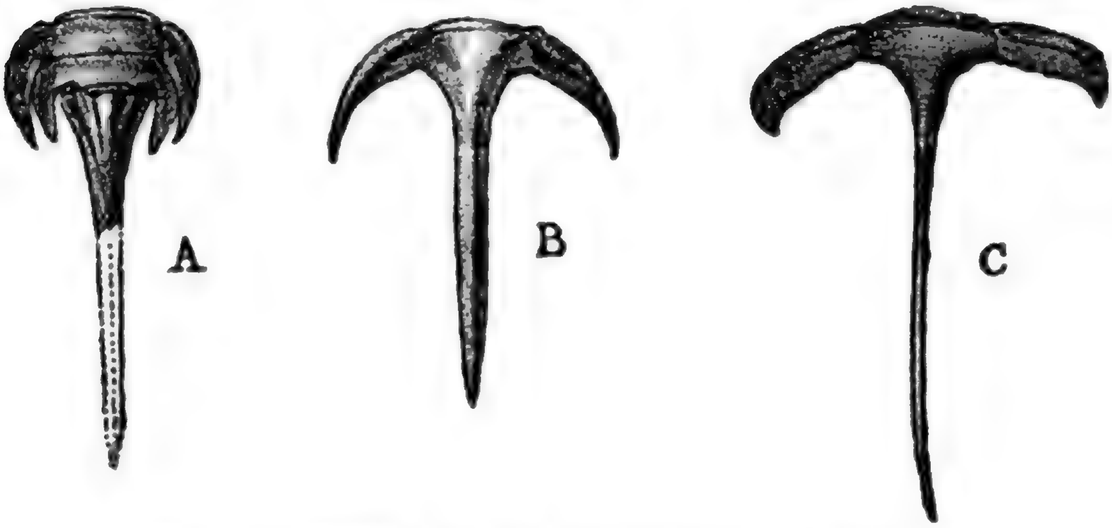
Having described these trilobites, I may now proceed to compare them among themselves and with other known Olenellids, and endeavour to correlate their homologous parts. In all the Olenellids the glabella and eye-lobes are so similar, that no difficulty arises in correlating part with part. It is not so with the marginal spines of the head-shield. The spines upon the pleural angles of the posterior margin in *Olenellus intermedius*, Pl. XXXII. fig. 7, and so strongly pronounced in *Olenelloides*, Pl. XXXII. figs. 1–6, are represented in the other forms in the collection by the rounded-off pleural angles. They have been shown by Ford and Walcott to be present in young stages of the American *Mesonacis* (*Olenellus*) *asaphoides*, Pl. XXXII. fig. 11, and to disappear into the rounded pleural angles in the adult. They are present as spines in *Holmia* (*Olenellus*) *Kjerulfi*, Pl. XXXII. fig. 12, and in the other described species of this genus. A study of fig. 12 (after Holm) reveals that they are, in all probability, the pleural spines of a segment comparable with one of the free body-segments, the traces of the axis and pleura of which have not been obliterated by its fusion with the other segments of the head-shield.

The genal spines of most Olenellids occupy the postero-lateral angles of the head-shield. That this was not their original position is made almost certain by the researches of S. W. Ford and Walcott, who have shown that in some of the young stages of *Olenellus Gilberti*, Pl. XXXII. fig. 9, these spines may be produced in a line with the anterior margin, and that they travel round as the animal gets older, Pl. XXXII. fig. 10. In *Olenelloides*, Pl. XXXII. figs. 1–6, we have an adult form which shows these spines placed about halfway between the anterior and posterior margins. That they have travelled back from a more anterior position is rendered probable by the margin behind them being concave. If that be the case, the notch between the genal spines and the pleural angles in *Olenellus*, *Holmia*, and *Mesonacis* represents what has once been a lateral margin. This inference is supported by evidence gained from the study of the ornamentation on *Olenellus*. In the paper read before this Society in 1892 I pointed out that the polygonal pattern of the test becomes highly elongated on the thickened

[illegible]

The absence of faceted pleura shows that these Olenellids had not acquired the habit of rolling up, so that dorsal spines such as those found on *Mesonacis* and *Holmia* were probably protective. If so, one asks, what was the nature of the enemies from which these creatures had to defend themselves? We may infer that

Fig. 2.



A = *Olenellus reticulatus*, last two body-segments and telson.
B = *Mesonacis Mickwitziæ*, eighth body-segment. (After Schmidt.)
C = *Mesonacis asaphoides*, thirteenth body-segment. (After Walcott.)

they were large, for *Holmia Bröggeri* and *Mesonacis asaphoides* are of considerable size. That small enemies preyed upon them, living or dead, is made certain by the occurrence in the collection under review of *Olenellus*-spines which have been bored by some annelid or other animal before fossilization, Pl. XXXII. figs. 13–15. The strong spiniform telson may have been used by *Olenellus* for purposes similar to that fulfilled by the telson in the recent *Limulus*.

The study of these Olenellids plainly shows them to have been very primitive trilobites. They have all their body-segments free. Their glabella is long and cylindrical, and divided into lobes by well-marked furrows. Their eye-lobes are outgrowths from the glabella, and have not wandered far from the primitive axis of the body. There is good evidence for the belief that the occipital or nuchal ring has been once a free segment, and the last to be added to the head-shield, and that the genal spines have travelled back from a more anterior position.

Of all the Olenellids yet described *Holmia* (*Olenellus*) *Kjerulfi* is the most generalized. None of its body-segments are so specialized as to make it conspicuous among its fellows, nor are any of its spines, except the genal ones, more elongated than its neighbours. Its nuchal or occipital segment is much like one of its free segments, but it is fused to the preceding segment instead of being articulated with it. Its genal spines are intermediate in position between those of *Olenelloides* and *Olenellus*, in which respect it is not quite so primitive as the former. From it all the other forms as yet

described, except *Olenelloides*, could easily be produced by exaggeration or suppression of some of its spines, or by addition to or diminution from the number of its body-rings. From *Holmia* (*O.*) *Kjerulfi* (Linnarsson), as a central type, it would require a less amount of modification to produce the *H.* (*O.*) *Callavei* (Lapworth) of Shropshire than the *H.* (*O.*) *Bröggeri* (Walcott) of Newfoundland; and in like manner the *Mesonacis* (*O.*) *Mickwitziæ* (Schmidt) of Russia than the *M.* (*O.*) *vermontana* (Hall) or *M.* (*O.*) *asaphoides* (Emmons) of America. Further, the species of *Olenellus* found in the North-west Highlands of Scotland would require less modification than the *Olenellus Thompsoni* (Hall) or *O. Gilberti* (Walcott) of America. The consideration of these points makes it probable that the dispersal of the Olenellids was from the Old towards the New World.

EXPLANATION OF PLATES XXIX.-XXXII.

Plate XXIX.

Fig. 1. *Olenellus Lapworthi.* Underside, with imperfect labrum in place. Enlarged 2 diameters. From 'Fucoid Beds,' Meall a' Ghubhais, Kenlochewe, Ross-shire. M. 4085^{d}.[1]

Fig. 2. *O. Lapworthi.* Enlarged 2 diameters. Same locality and formation. M. 4078^{d}.

Fig. 2*a*. *O. Lapworthi.* Counterpart of fig. 2. M. 4078da.

Fig. 3. *O. Lapworthi*, var. *elongatus.* Enlarged 2 diameters. Same locality. M. 4080^{d}.

Fig. 4. *O. Lapworthi*, var. *elongatus.* Enlarged 2 diameters. Same locality. M. 4089^{d}.

Fig. 4*a*. *O. Lapworthi*, var. *elongatus.* Counterpart of fig. 4. M. 4089da.

Fig. 5. *O. Lapworthi*, var. *elongatus.* Enlarged 2 diameters. Labrum supposed to belong to this variety. Same locality.

Fig. 6. *O. Lapworthi*, var. *elongatus.* Enlarged 2 diameters. Pleuron of third segment. Same locality.

Plate XXX.

Fig. 1. *Olenellus reticulatus*, nat. size. From 'Fucoid Beds,' Meall a' Ghubhais, Kenlochewe, Ross-shire. M. 4076^{d}.

Fig. 2. *O. reticulatus*, nat. size. Underside of head-shield. Same locality. M. 4104^{d}.

Fig. 3. *O. reticulatus.* Portion of fig. 2, enlarged, to show nature of ornamentation.

Fig. 4. *O. reticulatus*, nat. size. Same locality. M. 4161^{d}.

Fig. 5. *O. reticulatus*, nat. size. Fragment of head-shield. Same locality. M. 4093^{d}.

Fig. 6. *O. reticulatus*, nat. size. Underside of right pleuron of third body-segment. Same locality. M. 4103^{d}.

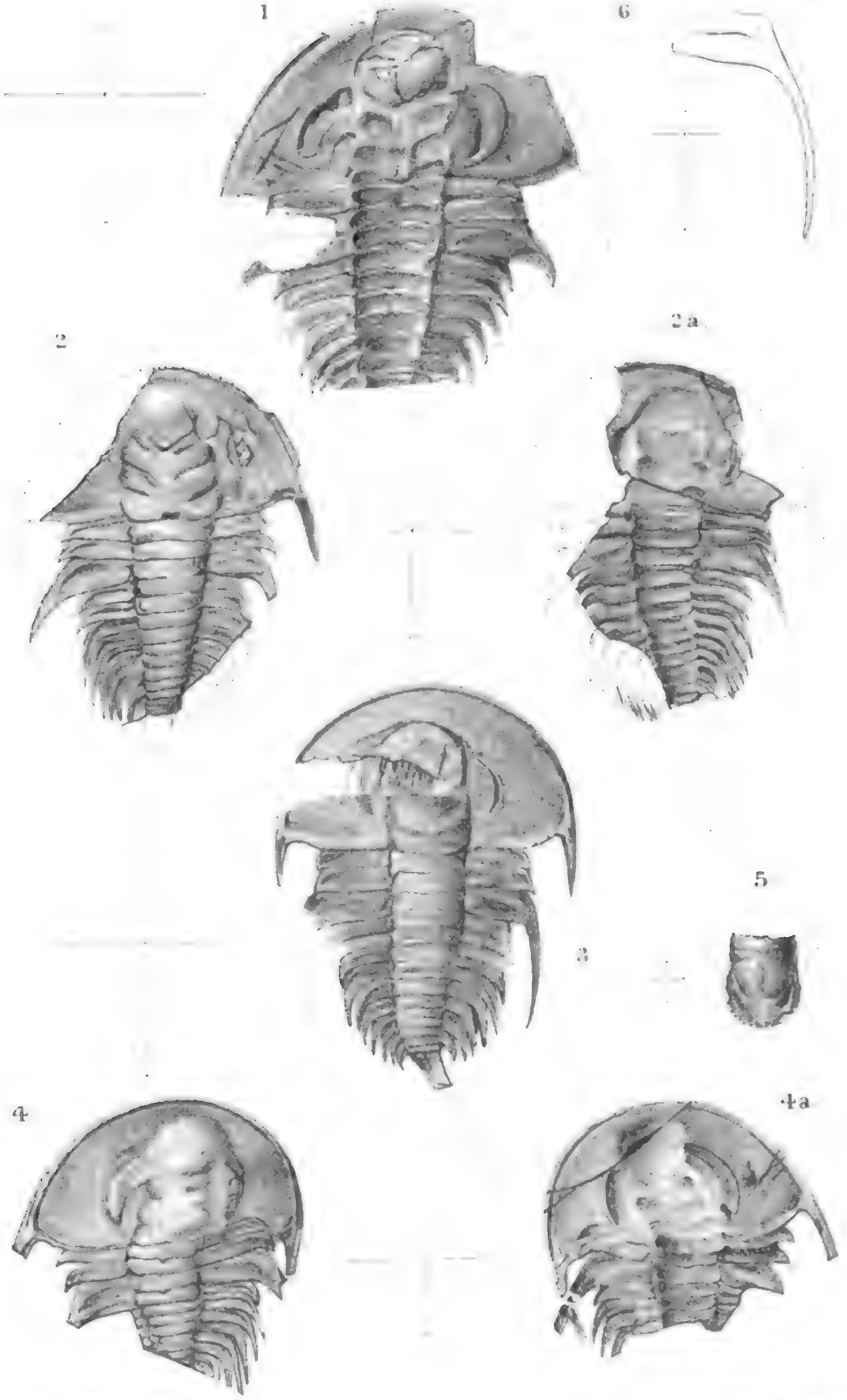
Fig. 7. *O. Lapworthi.* Enlarged 3 diameters. Third body-segment. Same locality.

Fig. 8. *O. reticulatus.* Last four segments enlarged, to show pleura and rudimentary spines on axes. Same locality. M. 4078^{d}.

Fig. 9. *O. reticulatus.* Last three segments magnified, to show pleura and spines on axes. Same locality. M. 4109^{d}.

Fig. 10. *O. reticulatus.* Body-segments from the tenth to the thirteenth inclusive, magnified to show pleura and spines on axes. Same locality. M. 4102^{b}.

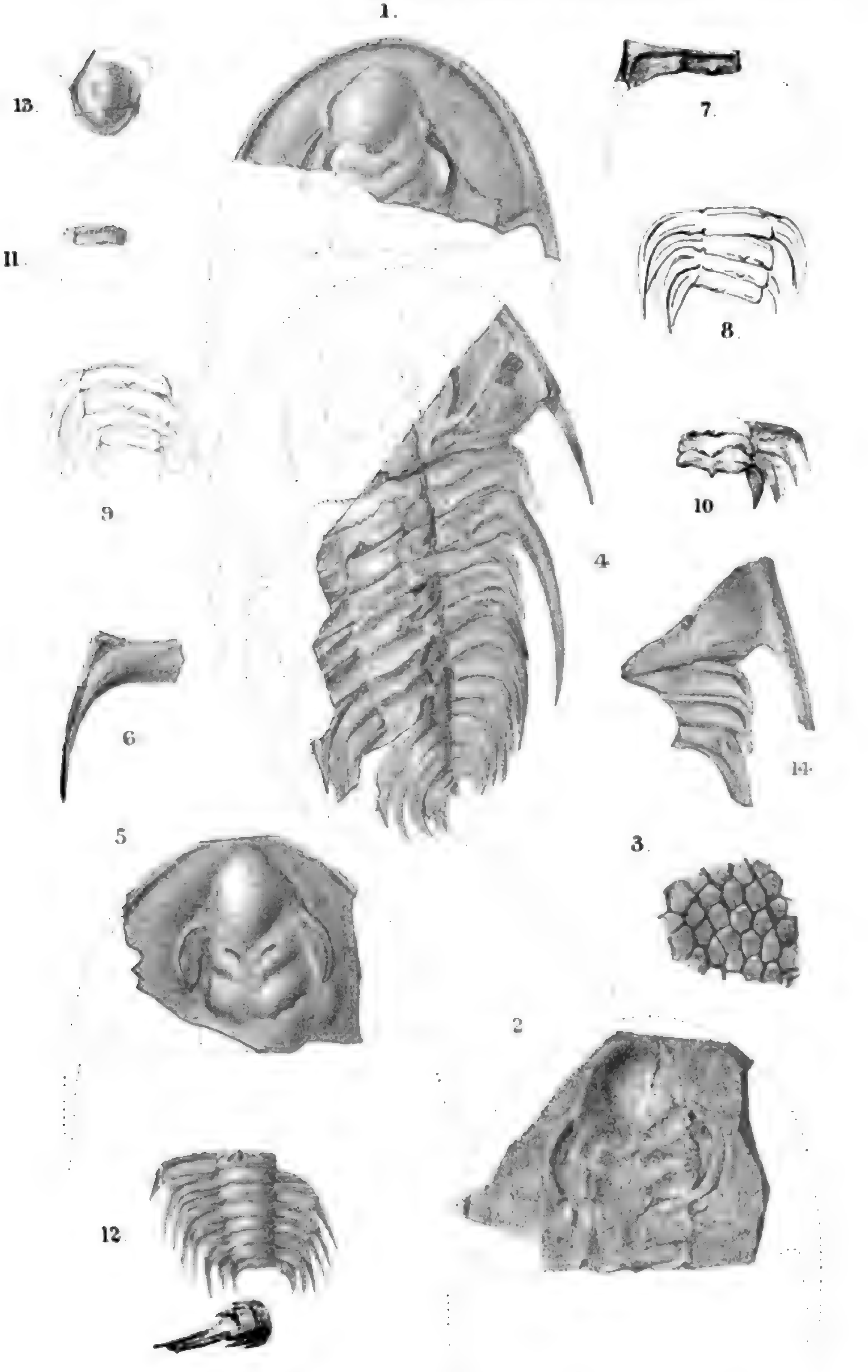
[1] These are the registered numbers of the specimens in the List-books of the Geological Survey of Scotland. The M stands for Macconochie.



B. N. Peach del. F. H. Michael lith.

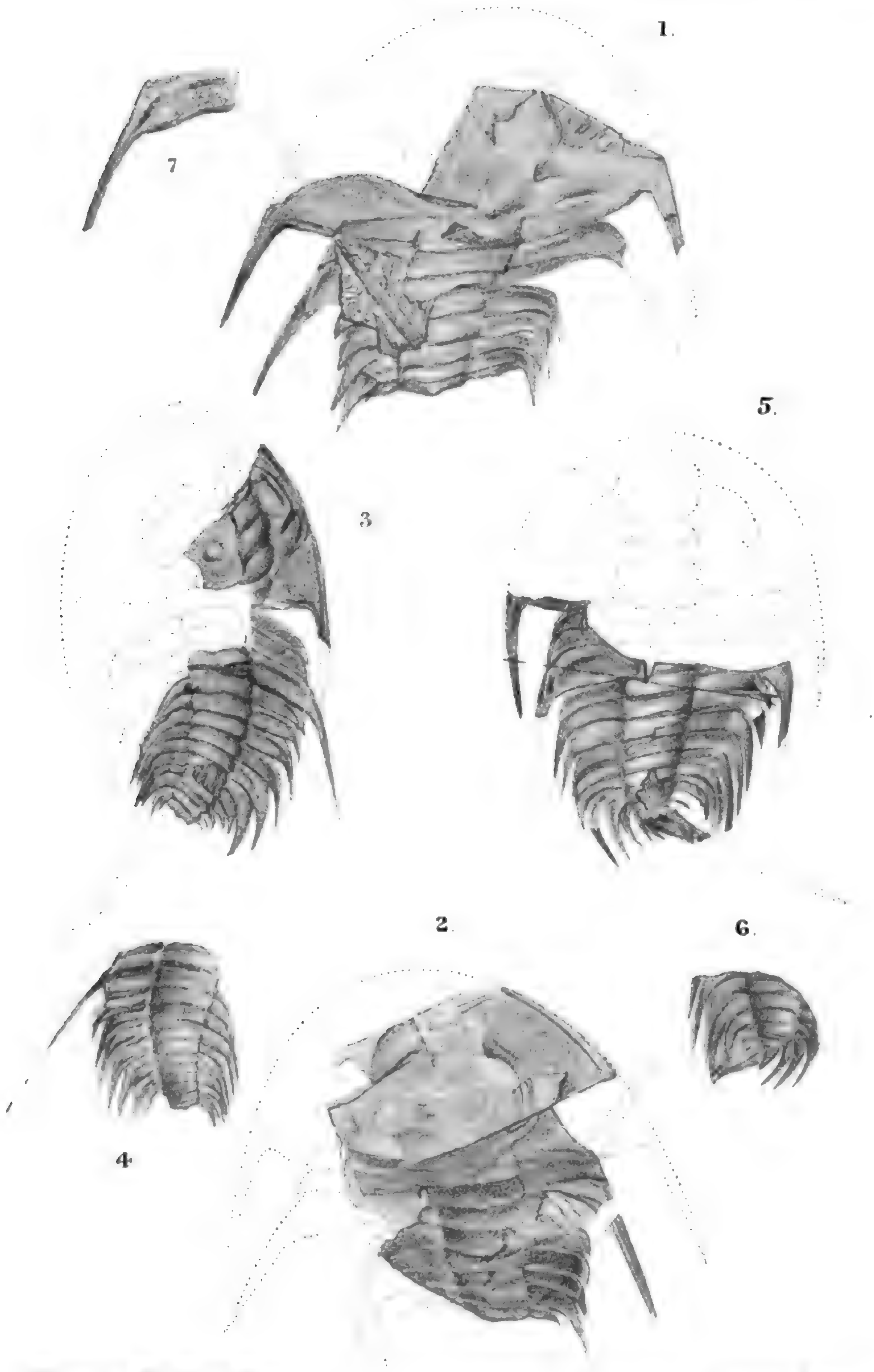
Mintern Bros. imp.

OLENELLUS LAPWORTHI.



B. N. Peach del. F. H. Michael lith. Mintern Bros. imp.

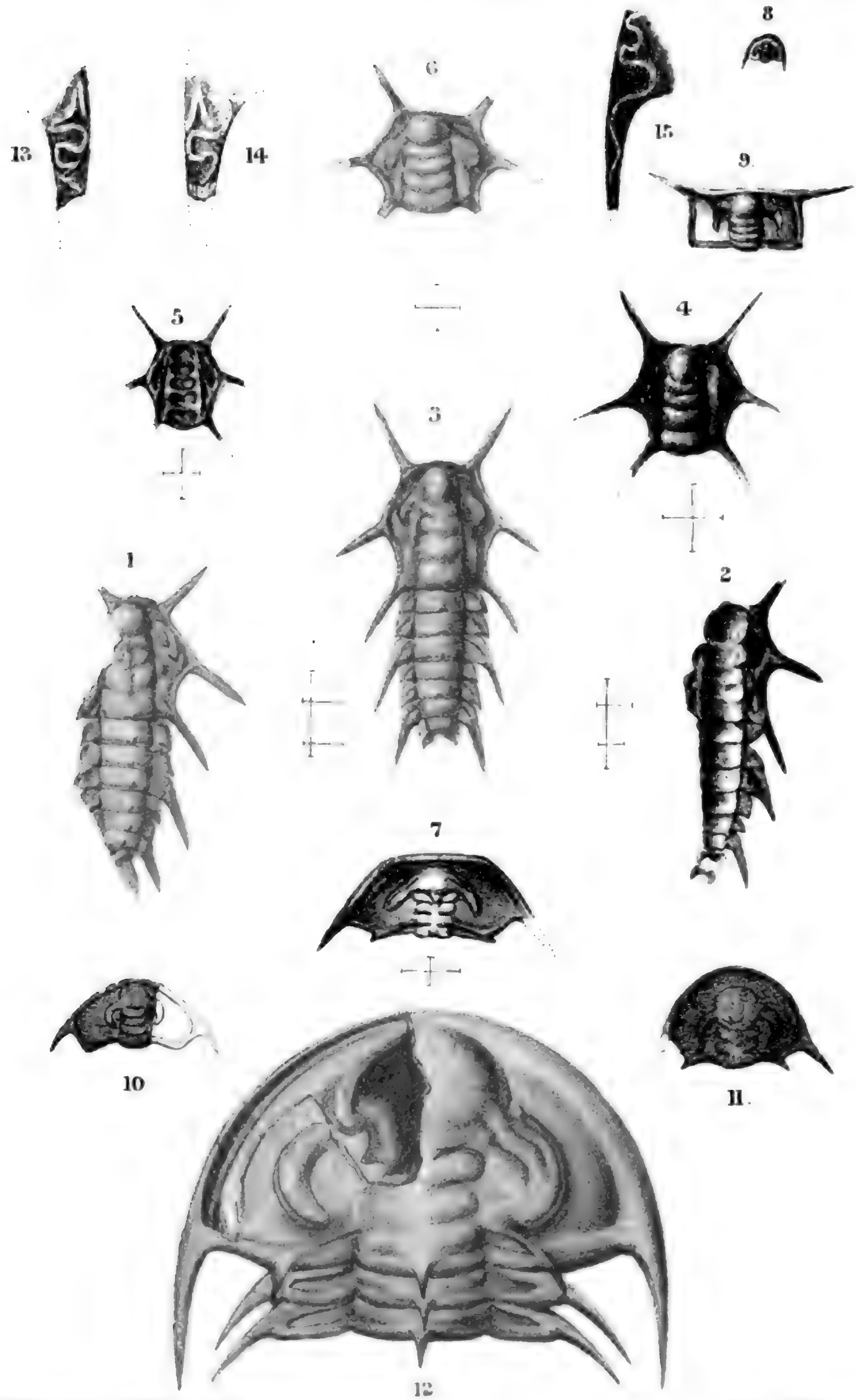
OLENELLUS RETICULATUS
& O. LAPWORTHI



B. N. Peach del. F. H. Michael lith.

Mintern Bros. imp.

OLENELLUS RETICULATUS.



B. N. Peach del. F. H. Michael lith. Mintern Bros. imp.

OLENELLOIDES, OLENELLUS, MESONACIS & HOLMIA

Fig. 11. *O. reticulatus.* Detached body segment from posterior part of body, nat. size, to show rudimentary spine on axis.

Fig. 12. *O. reticulatus*, nat. size. Showing several body-segments and the nature of the articulation of the telson. Same locality. M. 4077[d].

Fig. 13. *O. reticulatus*, nat. size. Detached labrum, supposed to belong to an individual of this species. 'Fucoid Beds,' Allt an Righ Jan, Dundonnell, Ross-shire.

Fig. 14. *O. reticulatus.* Portion of largest individual observed.

Plate XXXI.

Fig. 1. *Olenellus reticulatus*, nat. size. Shows the first two body-segments telescoped into the head-shield, the body being bent over at the eighth segment. Telson seen where the pleura or the left side have broken away, with counterpart. From 'Fucoid Beds,' Meall a' Ghubhais, Kenlochewe, Ross-shire. M. 4142[d].

Fig. 2. *O. reticulatus*, nat. size. Counterpart of fig. 1.

Fig. 3. *O. reticulatus*, nat. size. Distorted by the glabella being driven obliquely over the cheek. Same locality. M. 4078[d].

Fig. 4. *O. reticulatus.* Counterpart of fig. 3.

Fig. 5. *O. reticulatus*, nat. size. Same locality. M. 4091[d].

Fig. 6. *O. reticulatus.* Counterpart of part of fig. 5.

Fig. 7. *O. reticulatus*, nat. size. Left pleuron of third body-segment. Same locality.

Plate XXXII.

Fig. 1. *Olenelloides armatus.* Enlarged 3 diameters, showing the outer side of the right half. 'Fucoid Beds,' Meall a' Ghubhais, Kenlochewe, Ross-shire. M. 4111[d].

Fig. 2. *O. armatus.* Enlarged 3 diameters, showing the inside view of the left side. Counterpart of fig. 1. M. 4111[da].

Fig. 3. *O. armatus.* Enlarged 3 diameters. Dorsal view of 1 and 2 combined.

Fig. 4. *O. armatus.* Enlarged 3 diameters. Broad head-shield. Same locality. M. 4116[d].

Fig. 5. *O. armatus.* Enlarged 3 diameters. View of inside of elongated head-shield. Same locality. M. 4117[d].

Fig. 6. *O. armatus.* Enlarged 3 diameters. Medium form of head-shield. Same locality. M. 4127[d].

Fig. 7. *Olenellus intermedius.* Enlarged 3 diameters. Head-shield. Same locality. M. 4149[d] and 4149[da].

Fig. 8. *O. Lapworthi*, nat. size. Small head shield, to compare with figs. 4–7, showing that in this species the genal spine is at the posterior angles even in young individuals. Same locality.

Fig. 9. *O. Gilberti* (Walcott), after Ford and Walcott. Young stage, where the genal spines are placed far in advance, and given off in almost the same straight line as the anterior margin.

Fig. 10. *O. Gilberti* (Walcott), after Ford and Walcott. Young stage, in which the genal spines have travelled a little farther round than in fig. 9.

Fig. 11. *Mesonacis* (*O.*) *asaphoides* (Emmons), after Walcott. Young stage, in which the spines are still retained at the pleural angles.

Fig. 12. *Holmia* (*O.*) *Kjerulfi* (Linnarsson), after Holm, showing the head-shield and the first two free body-segments. Portion of the glabella is removed, to show the labrum in position beneath.

Fig. 13. Spine of *Olenellus gigas* bored by annelid? Nat. size. Meall a' Ghubhais, Kenlochewe, Ross-shire.

Fig. 14. Counterpart of fig. 13.

Fig. 15. Spine of *Olenellus*, bored by annelid? Nat. size. Same locality.

Discussion.

Dr. Hicks said it was highly satisfactory to find that such important additions had been made to the *Olenellus*-fauna of the North-west Highlands. He would have liked to hear further details than could be given in the abstract just read, especially as to whether the new species marked distinct zones or whether they occurred together. In the *Paradoxides*-beds in South Wales, the new species did not occur together, but were separated by various thicknesses of beds. Where the deposits were sandstones the range was much greater than where they were made up of finer materials. The *Olenellus*-zone at St. David's was separated by over 800 feet of sandstone beds from the lowest *Paradoxides*-zone, and the latter by nearly 2000 feet of strata from the highest *Paradoxides*-zone. There were no less than five distinct zones, each marked by a new species. He had found it necessary from the first, more than 30 years ago, to mark the zones with great care, and it was by that means, when working afterwards in North Wales, that Mr. Salter, Mr. Homfray, and himself were able to correlate the various subdivisions with those at St. David's. He further said that in 1875 he prepared a map, which is published in the Quart. Journ. of the Society (vol. xxxi. pl. xxvii.). In that map he gave the distribution of the Cambrian and Lower Silurian faunas over the European area, and he stated in the paper which it illustrated that he thought the migrations were from the Atlantic in a north-easterly direction over Europe, and in a north-westerly direction over America.

Dr. G. J. Hinde also spoke.

42. *The* Bargate Beds *of* Surrey *and their* Microscopic Contents. By Frederick Chapman, Esq., F.R.M.S. (Communicated by Prof. T. Rupert Jones, F.R.S., F.G.S. Read June 20th, 1894.)

[Plates XXXIII. & XXXIV.]

Contents.

I. Introduction.

That division of the Lower Greensand known as the Bargate Beds is of especial interest on account of the varied character of its organic and inorganic constituents, many of which are derived from older rocks.

In 1856[1] R. A. C. Godwin-Austen wrote in reference to these beds: "Whatever may have been the original range of the Oolitic group over the area now covered by the Wealden and Cretaceous formations of the S.E. of England, there is evidence that it has been reduced by the abrading action of the Lower Greensand sea along its coast-line. The shingle-beds of the Lower Greensand of Surrey and Kent contain, in addition to the materials already alluded to, a considerable number of extraneous fossils, such as the bones and teeth of Oolitic Saurians, *Ammonites Lamberti* and *A. crenatus* of the Oxford Clay, in great abundance, together with *Terebratula fimbria* and *Rhynchonella oolitica.*"

The correlation of these Bargate Beds, with others of Lower Greensand age in the area east of that where the first-mentioned occur, cannot be regarded as settled. The Bargate Beds have been placed by the Geological Survey at the top of the Hythe series,[2] whilst Mr. C. J. A. Meyer regards them as forming the basement beds of the uppermost or Folkestone series.[3]

It is not my intention here to discuss at any length their stratigraphical relations; but a summary of the evidence gathered after some detailed work in the Guildford and Dorking districts may be of some use in correlating these strata. It has led me to regard these beds, which are intermediate between the Folkestone and Hythe series, as fairly distinct from the upper and lower series

[1] Quart. Journ. Geol. Soc. vol. xii. p. 71.
[2] W. Topley, Geol. Surv. Mem. 'The Geology of the Weald,' 1875, p. 121.
[3] 'On the Lower Greensand of Godalming,' 1868, p. 10; in Suppl. to vol. i. Proc. Geol. Assoc. (1870)

[illegible]

Commencing above the ash-coloured sand (evidently of Hythe age, which therefore does not here concern us), 12 feet of which is seen, there is a bed of greenish sand, about 3 feet thick. In its lower half this bed is coarsely current-bedded, and the lamination strongly marked by carbonaceous bands, with argillaceous material, which increases nearer the top. It contains many *remanié* fossils and a considerable proportion of oolitic ironstone-grains resembling those of the iron-shot sand of Lincolnshire, with the difference, however, that these Bargate grains appear somewhat flattened. There are also occasional doubly-terminated crystals of quartz. Foraminifera occur, but rarely, in the more argillaceous portions, amongst others *Textularia prælonga*, Reuss.

Next above is a band of variable thickness, usually about 3 inches, of large and small subangular pebbles in clay, including clay-ironstone concretions, pieces of oolitic ironstone, fragments of lydite, and waterworn pieces of ammonites and other fossils. From the pale ochreous clay of this band a rich assemblage of mostly minute foraminifera, ostracoda, and sponge-spicules was obtained. These are not abundant, and are only found after careful search. For the list of these and descriptions of new species, see p. 688.

Various minerals were obtained from the sand associated with this clay; and I am greatly indebted to Dr. W. Fraser Hume, F.G.S., for kindly supplying the following notes upon them:—

"The most numerous of the heavy minerals are undoubtedly the *zircons*. These occur in two forms: (*a*) as crystals, (*b*) as rounded grains. The largest crystal has a length of ·178 mm. and a breadth of ·044 mm. The mineral possesses all the usual characters. The rounded grains are far more numerous than the crystals above mentioned. These latter must have undergone considerable friction, for, not only have perfect pebbles of zircon been formed, but these have also been often fractured and sometimes apparently broken completely across.

"*Rutile*. These are not so numerous as the zircons. Two different kinds are observable. (1). Forms which at times show traces of a prismatic habit, but are generally in a more or less rounded condition. A typical specimen had a length of ·165 mm. and a breadth of ·075 mm. (2). The second variety occurs in grains, of a clear golden-yellow colour, and these are especially prominent owing to their high refractive index and strongly adamantine lustre

"*Tourmaline*. A few specimens of this mineral are present. They are of distinct prismatic habit, bounded by rhombohedral faces, these latter being generally only visible on one side.

"*Kyanite*. Cleavage-flakes of this mineral are by no means uncommon. These flakes are generally rectangular in shape, and with an average length of ·134 mm., the cleavage being well-marked parallel to the short axis. This mineral agrees with the kyanite figured from the Bagshot Sands of Hampstead Heath (Teall's 'British Petrography,' pl. xliv. fig. 2).

"*Quartz*. Occurs in well-rounded grains, which are limpid, or at most show minute lines due to the presence of gas-cavities.

"*Felspar.* These grains are mostly kaolinized.

"A few *glauconite*-grains also occur.

"The minerals present here are of the same size as those from the Bagshot Sands, and three times as large as those from the Chalk-marl of the Isle of Wight."

Overlying the layer of clay-with-pebbles is a band of finely laminated sand, with many small pebbles and occasional thin seams of clay (also containing microzoa): the thickness of this band is about 9 inches. Together with the pebbles in clay below, it is conspicuous in the quarry section, because of its greater resistance to weathering. Above these comes in a bed of pale current-bedded sand, averaging 3 feet in thickness.

This is overlain by a whitish siliceous bed of variable thickness, consisting of sponge-remains, including fragments of Lithistid sponges, together with detached spicules of other types.

The higher beds in the Littleton Quarry consist of pebbly sand with rolled fossils, and sandy strata alternating with layers of compact and generally ferruginous Bargate limestone, amounting altogether to about 18 feet. The lower portion of these beds is merely a loose calcareous grit, in the higher it is an exceedingly compact limestone. The harder rock is of a dark reddish-brown colour. On a fractured surface this rock shows numerous cleavage-surfaces of calcite, shell-fragments, and bright-green glauconitic particles.

In thin sections under the microscope the compact Bargate Stone is seen to consist of numerous rounded and subangular quartz-grains, chalcedony, a few scattered grains of glauconite, many fragments of shells such as *Terebratulæ* and *Exogyræ*, nearly all of which have been silicified, also traces of polyzoa, portions of Lithistid and Hexactinellid sponges, and numerous spines and other parts of echinoderms. These are all firmly cemented together by a ferrugino-calcareous matrix. The molluscan shell-fragments are often perforated by apparently two distinct species of boring algæ, one consisting of fine interlacing filaments, and the other of coarser perforations with branches at short intervals. Moreover, in thin sections of the limestone, teeth and bones of fish, etc., and occasionally the tests of foraminifera can be distinguished. Amongst the latter are *Textularia trochus*, d'Orb., *Gaudryina*, sp., and *Lagena lævis* (Mont.).

After dissolving this rock in weak hydrochloric acid, the residuum amounts to 65 per cent. The rock thus acted upon is, however, still cemented together by ferruginous material; and this, when removed by boiling in strong hydrochloric acid, is found to amount to 12 per cent.

Some of the bodies in the siliceous residue resemble the spines of certain species of *Hemipedina* and *Cidaris* from the Middle and Upper Oolite, but the Bargate specimens are very minute.

The chalcedonized sponge-spicules are of a pale bluish-grey colour, with a surface similar in appearance to ground-glass. There are many examples of distortion amongst the casts of the axial canals of

spicules, which have been preserved in green chalcedony, generally resembling the examples figured by Dr. Hinde.[1]

Among the casts of organisms preserved in green chalcedonic silica are numerous pale-green threads, sinuous, branched, or bent, which may be referred to the parasitic borings of minute plants in the shell-fragments, etc. The perforations appear to have been filled in with the chalcedony, the subsequent solution of the shell setting free the delicate casts of the tubes. From the siliceous residue have been obtained several fragments of shells which have themselves been silicified, and, having lost their inner layer of shell-substance, expose the interlacing filamentous casts still in place within the shell.

There are also some peculiar fasciculate and divergent masses of pale green chalcedony, composed of cylindrical rods connected by short bars or stolons. These objects are probably casts of polyzoa (see Pl. XXXIII. fig. 11).

One of the more remarkable specimens from the residue is what appears to be a portion of a calcareous alga allied to the Corallines (see Pl. XXXIII. fig. 9). It consists of three joints, each shorter and more circular in section than in *Corallina officinalis*, but very near that form. I submitted this specimen, with others of a more doubtful nature and somewhat resembling the external form of *Lithothamnion* (see Pl. XXXIII. fig. 8), to Graf zu Solms-Laubach of Strasburg, who remarks that "it is scarcely possible to be absolutely certain of their affinities beyond placing these fragile fossils, at the best, in the Algæ-group. However, I hold it very probable that no. 4 represents a *Corallina*. The form of the joints and the intermediate pieces agrees with it perfectly. No. 1 may well be one of the *Diploporæ*" (see Pl. XXXIII. fig. 10).

The arenaceous foraminifera in the residue are *Haplophragmium emaciatum*, Brady; *H. nonioninoides*, Reuss; *H. depressum*, Jones; *H. Humboldti*, Reuss; *H. irregulare* (Röm.); *Bulimina polystropha*, Reuss; *B. obliqua*, d'Orbigny; and *B. pyrula*, d'Orbigny.

III. The Bargate Beds below St. Martha's Chapel (Chilworth).

The Bargate Stone and Pebble-beds are seen in, perhaps, greater lithological variation (though not showing so great a development as westward and southward) in the lane leading to Great Halfpenny Farm, on the west side of St. Martha's Hill (Chilworth), than in any other locality. The following are roughly approximate measurements of the beds exposed in this lane:—

		ft.	in.
Bargate Series.	Pebbly sand, underlying Folkestone Beds. Bargate Limestone (much of it is oolitic). Pebbly beds, with clay-seams. (The foraminifera were obtained from this bed.)	15	0
	Soft sponge-bed, resting on hard sponge-bed. (Just above the Farm.)	8	0
	Pebbly bed, resting on Hythe Sand with ironstone	12	6

[1] Phil. Trans. Roy. Soc. vol. clxxvi. (1885) pt. ii. pl. xlv. figs. 15*a–e*.

examined the spicules from this bed and also from that at Littleton, and remarks upon them as follows:—"These beds with sponge-remains are very similar to those in the same formation at Godalming, Haslemere, Sevenoaks, and other places in Kent, Surrey, and Sussex. Thin layers of the rock are mainly composed of detached spicules of various forms, indiscriminately mingled together, and cemented by a siliceous deposit one to the other. The spicules are usually much fractured, and their original opal silica has been changed to chalcedony and quartz. In places they are not cemented together, and they can then be picked out from the sand-grains of the rock.

"The spicules belong to various forms of sponges. The styliform and pin-shaped forms are like those of the existing monactinellid genera *Axinella* and *Dirrhopalum* (from St. Martha's). The most numerous spicules are the trifid forms of the tetractinellid genus *Geodites*, of which at least four species are present, *G. robustus*, *G. obtusus*, *G. Gaudryi*, Fischer, sp. (all from St. Martha's and Littleton), and *G. Carteri* (from St. Martha's). There are also caltrop spicules of *Pachastrella* (from St. Martha's and Littleton). The Lithistida are represented by spicules of *Mastosia* (from St. Martha's), *Doryderma* (from St. Martha's and Littleton), and *Rhagadinia* (from Littleton). There are likewise fragments of the mesh and nodular masses of a hexactinellid sponge (from Littleton), which has not yet been determined."

Above this sponge-deposit, and on the west side of the road, is a large exposure of pebbly beds with intercalated clay-seams, containing many species of foraminifera and a few ostracoda.

Higher up the lane Bargate Stone begins to predominate, alternating with pebble-beds and calcareous grit. In the siliceous residue of the Bargate Stone from this spot *Bulimina obtusa*, d'Orb., and *Lagena globosa* (Mont.), silicified, were found, and also two specimens of a polyzoan, which have been determined by Dr. J. W. Gregory, F.G.S., as a species of *Heteropora*.

The Bargate Stone at this locality is extremely interesting, on account of the occurrence of calcareous oolitic grains and brecciated fragments of oolite in the rock (see fig. 2, p. 684). It seemed at first probable that the oolitic grains might have been formed with the rock in which they are found. Closer examination showed, however, that they had been derived from an older rock, since many exhibited signs of attrition, and had hard abrading particles still adhering to or pressed into them. Moreover, some of the grains were massed together, as they would appear in the original rock; and further, the quartz and other grains in the rock are perfectly free from calcareous deposit. These grains were evidently derived from a calcareous oolitic rock of loose texture, resembling some of the more friable 'roestones.' Other examples of Bargate Stone were mainly composed of breccia, derived from a compact oolitic limestone. One of the rock-specimens containing the calcareous oolitic grains is of a pale reddish-brown colour, with darker ferruginous streaks and veins; the weathered surface of the rock shows the oolitic grains quite distinctly. The rock is always

well preserved, and quartz-grains rarely occurring. Foraminifera, such as *Lagena lævis* (Mont.) and *Nodosaria radicula* (Linn.), are frequent in the fragments of oolite.

After a careful examination of these oolitic Bargate limestones there remains no doubt whatever as to the detrital character of the grains, especially as they occur associated with other rocks evidently remnants of beds of the same age, possessing the brecciated character. Moreover, the derived fragments and particles appear to have been deposited gently, and quickly following their disintegration, leaving the calcareous grains nearly as perfect as when they formed part of the parent rock. The source of the derived fragments was not, perhaps, very distant from the spot where these beds are now found.

The occurrence of these detrital oolitic grains raises some question as to the contemporaneity of the microscopic fossils found in the clays of the Bargate series. Judging from the somewhat mixed character of the facies, we probably have, in the assemblage collected, a few Jurassic forms (derived), mingled with other species indigenous to the Lower Greensand.

Prof. Judd, who has kindly examined my specimens, has called my attention to the similarity of these rocks with those from the Richmond well-boring, at a depth of between 1141′ 6″ and 1151′ 6″. The material of the 10-ft. band at Richmond[1] is manifestly derived from the disintegration of Great Oolite rocks, some of which were found lower down in the boring. Since the 10-ft. band contains oolite grains and some ostracoda, which are common to this and the Bargate Beds of Surrey, there is good reason to suppose that we have a thinned-out extension of the Bargate Beds represented in the series beneath Richmond.

The sections of the Richmond rocks from the 10-ft. band all more or less resemble those of the Bargate limestone, and especially one slide, marked with the depth of 1151 ft. 6 in., which shows great similarity to the Bargate oolitic rock, excepting that the colour of the Richmond rock is grey-black instead of yellow or brown (see fig. 3, p. 686).

It seems reasonable to conclude that the ridge of Great Oolite rocks may have been situated immediately north of the Lower Greensand outcrop in East Surrey, forming a subordinate axis, lying upon the great Palæozoic axis which underlies London. To allow for this proximity of the Jurassic Beds it would be necessary to believe in a sudden thinning-out in Surrey of the Wealden Beds, and also of the members of the Lower Greensand older than the Bargate Beds, to admit of the junction of the former with the Oolites; or, as Prof. Judd suggests, there is possibly a fault bringing up the Oolitic rocks against the Lower Greensand.

Above the Bargate Stone Beds at St. Martha's Hill are some pebble-beds passing upwards into true, reddish-coloured Folkestone Sands with quartz-pebbles. Farther up the lane very good exposures

[1] 'On the Nature and Relations of the Jurassic Deposits which underlie London,' Quart. Journ. Geol. Soc. vol. xl. (1884) p. 738.

VI. Ostracoda and Foraminifera of the Lower Greensand.

The Lower Greensand strata of the S.E. of England are remarkably poor in the actual tests of foraminifera and other minute fossils, the former being hitherto represented only by internal casts in glauconite. Nevertheless, since glauconite-grains play so important a part in the formation of these Greensand beds, foraminifera must have existed in prodigious abundance at the time when these deposits were laid down.

The Speeton Clay of Yorkshire, also the Hilsthon and other Neocomian beds in North Germany and elsewhere, have already yielded an abundant foraminiferal fauna.

It is interesting, therefore, to find the calcareous tests of foraminifera and the carapaces of ostracoda in the Bargate Beds of Surrey. Whether this entire fauna was contemporaneous with the beds in which it occurs has yet to be proved; nevertheless, it is noteworthy that among the species and varieties of foraminifera found there are undoubted Lower Greensand forms.

VII. Ostracoda from the Bargate Pebble-beds of Littleton and of St. Martha's Hill (Chilworth).

[These all belong to the *Cytheridæ*.]

1. Cythere vesiculosa, sp. nov. (Pl. XXXIII. fig. 1 *a*, *b*, *c*.)

Valve quadrate, but rounded in front and bluntly pointed posteriorly: the surface sloping away from the ventral margin to the front and dorsal edges. Ventral face flat with the edges of the valves forming a flanged border, which passes along the posterior end of the valve. Dorsal edge short, locally swollen beyond the anterior hinge and curving into the posterior edge behind. The surface of the valve is irregularly swollen with rounded lumpy prominences. There are four of these protuberances situated towards the dorsal and central area, and a large and more prominent one projecting from near the middle of the ventral edge of the carapace; the presence of this last process shows the species to have a slight affinity towards the genus *Cytheropteron*. Length $\frac{1}{53}$ in. (·47 mm.).

This species somewhat resembles *C. Cluthæ*, Brady, Crosskey, & Robertson,[1] and *C. globulifera*, Brady[2]; but it differs from them chiefly in the arrangement of the knobs.

Occurrence: one valve in clay of Bargate Pebble-beds, Littleton.

2. Cythereis ornatissima (Reuss).

Cytherina ornatissima, Reuss, 'Verstein. böhm. Kreideform.,' pt. ii. (1846) p. 104, pl. xxiv. figs. 12 & 18.

Cythereis ornatissima, Jones & Hinde, Mon. Cret. Entom. Suppl., Pal. Soc. (1890) p. 21, pl. ii. figs. 1–7, 15, 16; pl. iv. figs. 7, 8.

[1] Mon. Post-Tert. Entom., Pal. Soc. (1874) p. 153, pl. xiii. figs. 16, 17.
[2] *Ibid.* p. 155, pl. ix. figs. 18–20; pl. xii. figs. 11, 12; pl. xv. figs. 19, 20.

There are some worn specimens of this species (from the clay of the Bargate Pebble-beds at Littleton) which, on careful examination, show some faint reticulations of the test-surface, but are otherwise more typical of the species than those mentioned below. It is a common species in Upper Cretaceous strata.

Three valves only were found.

3. CYTHEREIS ORNATISSIMA (Reuss), var. RETICULATA, Jones & Hinde.

Mon. Cret. Entom. Suppl., Pal. Soc. (1890) p. 24, pl. i. figs. 67, 68, 77; pl. iv. figs. 9–12.

The only specimen found is less than one-half the average length of the specimens recorded in the Cretaceous Monograph, this being only $\frac{1}{60}$ in. (·42 mm.) in length. It is a characteristic Upper Cretaceous variety.

From clay of Bargate Pebble-beds, Littleton.

4. CYTHEREIS LONSDALEANA, Jones.

Mon. Cret. Entom. Suppl., Pal. Soc. (1890) p. 27, pl. i. figs. 40–42, 64–66.

This is a well-known form in Upper Chalk strata, and is also recorded from the Upper Oolite of Ridgeway, Dorset.

One valve from clay of Bargate Pebble-beds, Littleton.

5. CYTHERIDEA RETORRIDA, Jones & Sherborn.

Proc. Bath. N. H. & Antiq. F.-Club, vol. vi. (1888) no. 3, p. 260, pl. i. fig. 8 *a–c*.

This species was first described from the Fuller's-Earth clay of Midford, near Bath.

Four valves from clay of Bargate Pebble-beds, Littleton.

6. CYTHERIDEA SUBPERFORATA, Jones.

Quart. Journ. Geol. Soc. vol. xl. (1884) pp. 768 & 772, pl. xxxiv. figs. 25, 26.

The Bargate specimens agree in all particulars with the description and figures of the above species, which was first found in the junction-bed of the Oolite and Neocomian (?), and also in the Great Oolite, of the Richmond Well-boring in Surrey.

One valve from clay-seams in Bargate Pebble-beds, Littleton; and one from the Pebble-beds in the lane leading to Great Halfpenny Farm, below St. Martha's Chapel, Chilworth.

7. CYTHERIDEA ROTUNDATA, Chapman & Sherborn.

Geol. Mag. (1893) p. 349, pl. xiv. fig. 11.

A solitary and fragmentary valve was found in the clay of the Bargate series at Littleton, which possesses the peculiarly coarse pittings on the surface of the test shown in the Gault specimen.

8. CYTHERIDEA BICARINATA, Jones & Sherborn.

Proc. Bath N. H. & Antiq. F.-Club, vol. vi. (1888) no. 3, p. 270, pl. iv. fig. 5 *a–c*.

In this series there is only one specimen which can with some certainty be referred to the above species; this specimen, however, is destitute of the tuberculations of the exterior of the hinge-line such as are present on the specimens described from the Fuller's-Earth clay of Midford, but probably not of specific value.

One valve from clay of Bargate Pebble-beds, Littleton.

9. CYTHERIDEA BICARINATA, Jones & Sherborn, var. NODULOSA, nov. (Pl. XXXIII. fig. 2 *a*, *b*, *c*.)

This variety differs from the specific form, *C. bicarinata*, in having the two ventral carinæ terminating posteriorly in a nodulous prominence; and it also has a median longitudinal, with a feebler dorsal ridge; these two ridges also end in a similar lumpy process in the postero-dorsal region.

Six valves from clay-seams in Bargate Pebble-beds, Littleton.

10. CYTHERIDEA VELLICATA, sp. nov. (Pl. XXXIII. fig. 3 *a*, *b*, *c*.)

Valve subovate, broad in front, tapering and blunt behind, with a flanged posterior margin. Dorsal edge straight; ventral margin curved and steep, surmounted by a sharp keel running close to the edge. The central area is occupied by a low ridge, and near the postero-dorsal margin the surface is pinched up into a short keel raised posteriorly into a blunt process. Length of valve $\frac{1}{60}$ to $\frac{1}{50}$ in. (0·42 to 0·5 mm.).

Two valves from clay-seams in Bargate Pebble-beds, Littleton.

11. CYTHERIDEA FENESTRATA, sp. nov. (Pl. XXXIII. fig. 4.)

Valve subovate, with a steep ventral margin sloping away towards the front and back as in the above species *C. vellicata*, to which, as to ridges and shape, it bears much affinity. The surface is decorated on the dorsal side of the ventro-marginal ridge with angular or square-shaped pittings arranged in two series. This fenestrated surface of the test reminds one of *Cytheropteron fenestratum*, Brady [1]; that species, however, has the fenestration confined to one series of markings, besides being separated by generic differences. Length of valve $\frac{1}{50}$ in. (0·5 mm.).

One valve from clay of Bargate Pebble-beds, Littleton.

12. CYTHERIDEA CRATICULA, Jones & Sherborn.

Proc. Bath N. H. & Antiq. F.-Club, vol. vi. (1888) no. 3, p. 272, pl. iv. figs. 9 *a–c* and 10 *a–c*.

The specimens originally described by the above authors were from the Fuller's-Earth clay of Midford.

One valve from clay of Bargate Pebble-beds, Littleton.

[1] 'Challenger' Report, Zool., vol. i. (1880), G. S. Brady, Ostracoda, p. 139 pl. xxxiv. fig. 6, *a–d*.

13. Cytheridea bipapillata, sp. nov. (Pl. XXXIII. fig. 5 *a*, *b*, *c*.)

Valve suboblong; the surface gently and almost equally convex. The ventral edge is slightly steeper than the dorsal edge. The anterior margin rounded, with a flattened rim, narrow, but showing a distinct fluting of the surface. The valve is decorated with somewhat irregular square or polygonal pittings. At the antero-dorsal region are situated two round and low papillæ, placed close together. Length of valve $\frac{1}{50}$ in. (0·5 mm.).

One valve from clay of Bargate Pebble-beds, Littleton.

14. Cytheropteron concentricum (Reuss).

Cytherina concentrica, Reuss, 'Verstein. böhm. Kreideform.' pt. ii. (1846) pp. 104 & 105, pl. xxiv. figs. 22 *a–c*.

Cytheropteron concentricum, Jones & Hinde, Mon. Cret. Entom. Suppl., Pal. Soc. (1890) p. 31, pl. i. figs. 5–10, pl. iv. fig. 19.

This species has been recorded from Upper Cretaceous strata, from the Neocomian of Haute Marne, and from the Upper Oolite (?) of Dorset. The Bargate specimens still retain the delicate sculpturing of the test-surface, and their excellent preservation leads me to suppose that of these minute fossils some at least were living during the deposition of these beds, and that, unlike the calcareous oolitic grains found in the associated rocks, they may not have been derived from older strata.

Two valves from clay-seams of Bargate Pebble-beds, Littleton; and two from Pebble-beds of Halfpenny Lane below St. Martha's Hill, Chilworth.

15. Cytheropteron concentricum (Reuss), var. virginea, Jones.

Cythere punctatula (non Römer), var. *virginea*, Jones, Mon. Cret. Entom., Pal. Soc. (1849) p. 12, pl. i. fig. 2 *n*.

Cytheropteron concentricum, var. *virginea*, Jones & Hinde, Mon. Cret. Entom. Suppl., Pal. Soc. (1890) p. 32, pl. i. figs. 14–17.

This variety is known from many Upper Cretaceous deposits down to the Upper Greensand.

One fragmentary valve from clay of Pebble-beds, Littleton.

16. Cytheropteron subconcentricum (Jones).

Cythere subconcentrica, Jones, Quart. Journ. Geol. Soc. vol. xl. (1884) p. 768, pl. xxxiv. figs. 28, 29.

This species was originally described from the Junction-bed of the Oolite with the Neocomian (?) from the Richmond Well-boring.

One valve from clay-seams of Pebble-beds, Littleton.

17. Cytheropteron drupaceum (Jones).

Cythere drupacea, Jones, Quart. Journ. Geol. Soc. vol. xl. (1884) p. 772, pl. xxxiv. fig. 30.

This species was first described from the Great Oolite of the Richmond Well-boring.

One valve from clay-seams of Pebble-beds, Littleton.

18. CYTHEROPTERON LATICRISTATUM (Bosquet).

Cythere laticristata, Bosquet, Mém. Comm. Carte géol. Néerlande vol. ii. (1854) p. 108, pl. vii. figs. 11 *a–d*.

This species appears to form a link between *C. sphenoides* (Reuss) and *C. alatum* (Bosquet), the postero-ventral wing of the above species showing an intermediate stage of development. Bosquet obtained his specimens from Upper Cretaceous and Tertiary beds.

A very perfect and typical valve from clay of Pebble-beds, Littleton.

19. CYTHEROPTERON RETICULOSUM, sp. nov. (Pl. XXXIII. fig. 6 *a, b, c.*)

Valve subrhomboidal, with well-rounded anterior, and somewhat oblique and slightly beaked posterior margin. The postero-ventral process rises more anteriorly than in *C. umbonatum* (Will.)[1], and is less prominent. The area between this alar process and the antero-dorsal margin is marked with interrupted surface-reticulations. Length of valve $\frac{1}{55}$ in. (·45 mm.).

One valve from clay of Pebble-beds, Littleton.

20. CYTHEROPTERON COSTULIFERUM, sp. nov. (Pl. XXXIII. fig. 7 *a, b, c.*)

Side view of carapace, subovate, narrow, and rounded in front, but bluntly pointed behind. Valve thickest at one-third from the posterior end, sloping towards the antero-dorsal margins, and highest in the middle of the dorsal edge. The ventral face is nearly flat, hollowed slightly towards the ventral margins of the valves. Dorsal margin bordered with a flange which continues less strongly along the ventral margin. The ventral aspect shows the test-surface striated longitudinally with about four low and narrow costulæ on each valve; and the surface of the carapace also has several weak longitudinal ridges on each valve. The postero-ventral swelling resembles that of *C. concentricum*, var. *virginea*, Jones. Length of valve $\frac{1}{55}$ in. (0·45 mm.).

Two valves in conjunction, from clay-seams of Pebble-beds, Littleton.

Of the twenty species and varieties just enumerated, seven are apparently new; nine have been previously noticed from Cretaceous strata generally, whilst four are undoubted Jurassic forms.

[1] Mon. Cret. Entom. Suppl., Pal. Soc. (1890) p. 40, pl. i. figs. 21–26.

VIII. Foraminifera from the Bargate Beds, or their equivalents, at Littleton, St. Martha's Hill (Chilworth), Godalming, and Dorking.[1]

Family MILIOLIDÆ.

Subfamily Miliolininæ.

Miliolina, Williamson.

1. Miliolina agglutinans (d'Orbigny).

Quinqueloculina agglutinans, d'Orbigny, 'Foram. Cuba,' 1839, p. 168, pl. xii. figs. 11–13.

Miliolina agglutinans, Brady, 'Challenger' Rep. vol. ix. (1884) p. 180, pl. viii. figs. 6, 7; Chapman, Journ. Roy. Micr. Soc. (1891) p. 574, pl. ix. fig. 7.

Two specimens were met with, somewhat flatter on the broader surfaces than in d'Orbigny's typical quinqueloculine form, but closely resembling the variety found in the Gault (see last reference). This occurrence in Neocomian strata is the earliest recorded appearance of the species as a fossil.

From clay-seams in Bargate Beds at Holloway Hill, Godalming.

Subfamily Hauerininæ.

Planispirina, Seguenza.

2. Planispirina obscura, sp. nov. (Pl. XXXIV. fig. 1 *a*, *b*, *c*.)

Test discoidal and nearly circular in outline; compressed, slightly convex on one face and concave on the other. The concave side in the example found shows the first two or three whorls to be helicoid and non-septate (?), while the last whorl is arranged in the manner of a *Miliolina*. Aperture a narrow slit placed terminally. Diameter $\frac{1}{55}$ in. (·45 mm.).

The genus *Planispirina* has hitherto been confined to the Tertiary epoch, and is still represented in deep-sea deposits.

One specimen from clay-seams of Bargate Pebble-beds, Littleton.

Family LITUOLIDÆ.

Subfamily Lituolinæ.

Haplophragmium, Reuss.

3. Haplophragmium agglutinans (d'Orbigny).

Spirolina agglutinans, d'Orbigny, 'Foram. Foss. Vienne,' 1846, p. 137, pl. vii. figs. 10–12.

[1] The classification here employed is that given by the late H. B. Brady in the 'Challenger' Report on the Foraminifera, vol. ix. (1884), to which work I am also indebted for general references.

Haplophragmium agglutinans, Brady, 'Challenger' Rep. vol. ix. (1884) p. 301, pl. xxxii. figs. 19–26.

The example found is very characteristic, and exactly coincides with d'Orbigny's figures of the Tertiary specimens; it is easily distinguished from the other crosier-shaped species by the smallness and compression of the spiral portion of the test. The occurrence of this species in Neocomian beds helps to complete the record, from its first appearance in Lower Carboniferous rocks, through all important fossiliferous strata to the present time.

One specimen from Bargate Beds, Holloway Hill.

4. Haplophragmium Humboldti (Reuss).

Spirolina Humboldti, Reuss, Zeitschr. deutsch. geol. Gesellsch. vol. iii. (1851) p. 65, pl. iii. figs. 17, 18.

Haplophragmium Humboldti, Reuss, Denkschr. Ak. Wiss. Wien, vol. xxv. (1865) p. 119, pl. i. figs. 1–4; Hantken, Jahrb. ungar. geol. Anstalt, vol. iv. (1875) p. 11, pl. ii. figs. 3, 4.

This form is easily recognized by the cultration of the spiral portion of the test, that feature distinguishing it from the closely-allied form *H. irregulare* (Römer). It has previously been recorded from various strata of Tertiary age.

One example in the siliceous residue from the Bargate limestone, Littleton.

5. Haplophragmium irregulare (Römer).

Spirolina irregulare, Römer, 'Verst. nordd. Kreidegeb.' 1840, p. 98, pl. xv. fig. 29.

Haplophragmium irregulare, Reuss, Sitzungsb. Ak. Wiss. Wien, vol. xl. (1860) p. 219, pl. x. fig. 9, pl. xi. fig. 1.

This species has been noted from various Cretaceous beds in North Germany and Bohemia.

One specimen in siliceous residue from Bargate limestone and three in clay of Bargate series, Littleton.

6. Haplophragmium foliaceum, Brady.

H. foliaceum, Brady, 'Challenger' Rep. vol. ix. (1884) p. 304, pl. xxxiii. figs. 20–25.

The specimens met with in the Bargate Beds resemble the recent specimens of Dr. Brady in the extreme transparency of the thin arenaceous test; but they are probably arrested forms of the species, since the Neocomian specimens do not exhibit the crosier-shaped form caused by the linear arrangement of the later chambers.

Two specimens from clay of Bargate series, Holloway Hill.

7. Haplophragmium emaciatum, Brady.

H. emaciatum, Brady, 'Challenger' Rep. vol. ix. (1884) p. 305, pl. xxxiii. figs. 26–28.

A single specimen was found which evidently must be referred to the above species, since the coiling of the chambers is evolute;

one face of the test is fractured, showing the spiral of chambers filled up completely with glauconite.

From siliceous residue of Bargate limestone, Littleton.

8. Haplophragmium acutidorsatum, Hantken.

H. acutidorsatum, Hantken, Magyar Földt. Társulat, vol. iv. (1868) p. 82, pl. i. fig. 1; and Jahrb. ungar. geol. Anstalt, vol. iv. (1875) p. 12, pl. i. fig. 1.

The specimen from the Bargate series is quite typical in form, but not in size: Hantken's specimens being from 1 to 2·5 mm. in diameter, while the former is only 0·22 mm. The originally described specimens were from the Hungarian Tertiaries.

From clay of Bargate Pebble-beds, Littleton.

9. Haplophragmium neocomianum, sp. nov. (Pl. XXXIV. fig. 2 *a*, *b*.)

Test arenaceous, thin, planospiral, and involute. The septation is obscure, but usually about nine chambers appear on the test-surface; the last chamber is sometimes slightly produced at the outer angle. The surface of the test, which is nearly always of a brown colour, is undulated. Aperture an arched slit situated at the base of the terminal chamber. Diameter $\frac{1}{50}$ in. (0·5 mm.).

This species is nearly related to *H. fontinense*,[1] but the latter species is arranged on an evolute plan.

From clay-seams of Bargate Beds, Littleton (four specimens); from clay of Pebble-beds, Halfpenny Lane, Chilworth (one specimen); and from clay-seams in Bargate Beds, Holloway Hill (thirteen specimens).

10. Haplophragmium nonioninoides, Reuss.

H. nonioninoides, Reuss, Sitzungsb. Akad. Wissensch. Wien, vol. xlvi. (1862) p. 30, pl. i. fig. 8.

Some of the specimens from the Bargate series of the above species closely approach *H. canariense* (A. d'Orbigny's *Nonionina canariensis*)[2] in form—especially those which have the test constricted at the sutures and the chambers well inflated. Dr. Reuss's specimens of *H. nonioninoides* were obtained from the 'Flammenmergel' and the '*Minimus*-Thon' of North Germany, beds which are nearly the equivalent of the Gault in this country. It is also a well-known foraminifer in the English Gault.

One specimen from siliceous residue of Bargate limestone, and nine from clay of Pebble-beds, Littleton; one from Pebble-beds of Halfpenny Lane, Chilworth; and three from Bargate Beds, Holloway Hill.

11. Haplophragmium depressum, Jones.

H. depressum, Jones, Quart. Journ. Geol. Soc. vol. xl. (1884) p. 765, pl. xxxiv. fig. 2.

This species was described by Prof. T. Rupert Jones from the

[1] Terquem, Mém. Acad. Imp. Metz (1870), p. 235, pl. xxiv. figs. 29, 30.

[2] D'Orbigny, 'Foram. Iles Canaries,' 1839, p. 128, pl. ii. figs. 33, 34.

T. charoides, Carpenter, 'Introd. Foram.' 1862, p. 141, pl. xi. fig. 3.

Ammodiscus charoides, Brady, 'Challenger' Rep. vol. ix. (1884) p. 334, pl. xxxviii. figs. 10–16.

The Bargate specimens of the above species are rather minute, measuring only from $\frac{1}{100}$ to $\frac{1}{85}$ inch (0·25 to 0·3 mm.). The test is quite white and has a perfectly smooth surface. *A. charoides* is known from the Swiss Jurassic, and also from Tertiary and recent deposits.

In the Bargate series it was found at Littleton only, in the clay of the Pebble-beds (three specimens).

15. Ammodiscus pleurotomarioides, sp. nov. (Pl. XXXIV. fig. 3 *a*, *b*, *c*.)

Test coarsely arenaceous, consisting of a helicoid spiral of four whorls. The basal aspect of the test is excavate, and the separate whorls are not distinctly seen. The opposite face of the test is convex. Diameter of test $\frac{1}{40}$ inch (0·63 mm.); height $\frac{1}{120}$ inch (0·21 mm.).

This species is perhaps more nearly allied to *A. gordialis* than to any other species of *Ammodiscus*; especially since some examples of the latter species have an irregular helicoid method of growth, with the flat side more or less excavate.[1] It also appears to be isomorphous with the perforate form *Spirillina obconica*, Brady.[2]

One specimen from Bargate Pebble-beds, Littleton.

Trochammina, Parker and Jones.

16. Trochammina squamata, Jones & Parker, var. limbata, nov. (Pl. XXXIV. fig. 4 *a*, *b*, *c*.)

Test finely arenaceous, whitish and translucent. This variety differs from the type-form *T. squamata*[3] in having the margins of the chambers composed of transparent test-material. The test has usually fewer convolutions than the type form, there being, as a rule, two, or at the most three, while there are in *T. squamata* as many as four. Diameter of the test $\frac{1}{240}$ to $\frac{1}{50}$ inch (0·1 to 0·5 mm.).

From Pebble-beds, Littleton (five specimens); from clay of Bargate Beds, Holloway Hill (six); and from beds below Folkestone series, Horsham Road, Dorking (thirty-eight).

[1] See Burrows, Sherborn, & Bailey, Journ. Roy. Micr. Soc. 1890, p. 552, pl. viii. fig. 7; also Chapman, Journ. Roy. Micr. Soc. 1892, p. 327, pl. vi. fig. 13.

[2] Quart. Journ. Micr. Sci. vol. xix. n. s. (1879) p. 279, pl. viii. fig. 27 *a*, *b*. Also 'Challenger' Rep. vol. ix. (1884) p. 630, pl. lxxxv. figs. 6, 7.

[3] Jones & Parker, Quart. Journ. Geol. Soc. vol. xvi. (1860) p. 304; Carpenter, 'Introd. Foram.' 1862, p. 141, pl. xi. fig. 1; Brady, 'Challenger' Rep. vol. ix. (1884) p. 337, pl. xli. fig. 3 *a*–*c*.

Family TEXTULARIIDÆ.

Subfamily TEXTULARIINÆ.

TEXTULARIA, Defrance.

17. TEXTULARIA SAGITTULA, Defrance.

T. sagittula, Defrance, Dict. Sci. Nat. vol. xxxii. (1824) p. 177, vol. liii. p. 344; Atlas Conch. pl. xiii. fig. 5; Brady, 'Challenger' Rep. vol. ix. (1884) p. 361, pl. xlii. figs. 17, 18.

To this species must be assigned some Bargate specimens which are compressed, cuneiform, or sagittate, and with more or less sharp edges. These Neocomian specimens are, however, about one-third the usual size, their average length being only $\frac{1}{100}$ inch (0·25 mm.).

T. sagittula has hitherto made its first appearance in Upper Cretaceous beds (Gault and Chalk), and is fairly common in all newer deposits up to the present time.

Eight specimens from beds below Folkestone series in Horsham Road-cutting, Dorking.

18. TEXTULARIA GRAMEN, d'Orbigny.

T. gramen, d'Orbigny, 'Foram. Foss. Vienne,' 1846, p. 248, pl. xv. figs. 4, 6; Brady, 'Challenger' Rep. vol. ix. (1884) p. 365, pl. xliii. figs. 9, 10.

This species occurs in the Bargate series, but is smaller than usual; in some cases the specimens closely approach *T. globulosa*, Ehrenberg,[1] in the inflation of the last two chambers.

From Pebble-beds, Littleton (six specimens); in Bargate Beds, Holloway Hill (two); and in beds below Folkestone series, Horsham Road, Dorking (two).

19. TEXTULARIA PRÆLONGA, Reuss.

T. prælonga, Reuss, 'Verstein. böhm. Kreid.' pt. i. (1845) p. 39, pl. xii. fig. 14.

This species is represented from the Bargate series by one specimen from the Littleton Pebble-beds, and one from the beds below the Folkestone series, Horsham Road, Dorking.

20. TEXTULARIA MINUTA, Berthelin.

T. minuta, Berthelin, Mém. Soc. géol. France, sér. 3, vol. i. (1880) no. 5, p. 26[2]; Chapman, Journ. Roy. Micr. Soc. 1892, p. 327, pl. vi. fig. 15.

The examples found are similar to those from the Folkestone Gault both in size and form.

Five specimens from Bargate Pebble-beds, Littleton.

[1] Abhand. Ak. Wiss. Berlin (1838), 1839, p. 135 (no. 60), pl. iv. fig. β.

[2] This species is the same as that figured by Reuss under the name of *T. pygmæa*, Sitzungsb. Ak. Wiss. Wien, vol. xlvi. (1862) p. 80, pl. ix. fig 11; the specific term *pygmæa* having been previously used for another Textularian type by A. d'Orbigny, it was afterwards renamed by Berthelin to avoid confusion.

21. TEXTULARIA AGGLUTINANS, d'Orbigny.

T. agglutinans, d'Orbigny, 'Foram. Cuba,' 1839, p. 136, pl. i. figs. 17, 18, 32–34; Chapman, Journ. Roy. Micr. Soc. 1892, p. 329, pl. vi. fig. 21.

The specimens from the Bargate series are very small, but bear all the characters of the above species. It is interesting to note this form as occurring in the Neocomian beds, having been lately found in the Gault, though previously unknown from beds older than the Tertiaries.

Three specimens from Pebble-beds, Littleton.

22. TEXTULARIA TROCHUS, d'Orbigny.

T. trochus, d'Orbigny, Mém. Soc. géol. France, vol. iv. (1840) p. 45, pl. iv. figs. 25, 26.

This species is already known from Cretaceous and Tertiary strata. The only isolated specimen found in the Bargate series is a replacement of the test in green chalcedonic silica; but several examples of the same species have been noted in thin sections of Bargate limestone. All the specimens were from Littleton.

23. TEXTULARIA TURRIS, d'Orbigny.

T. turris, d'Orbigny, Mém. Soc. géol. France, vol. iv. (1840) p. 46, pl. iv. figs. 27, 28.

This species is also known from Cretaceous and newer strata.

Two rather small specimens from Bargate Pebble-beds, Littleton, measuring $\frac{1}{85}$ inch (0·3 mm.) in length.

VERNEUILINA, d'Orbigny.

24. VERNEUILINA TRIQUETRA (Münster).

Textularia triquetra, Münster (in Römer's paper), Neues Jahrb. 1838, p. 384, pl. iii. fig. 19.

Verneuilina triquetra, Brady, 'Challenger' Rep. vol. ix. (1884) p. 383, pl. xlvii. figs. 18–20.

The Bargate specimens are very minute, being only $\frac{1}{70}$ inch (0·35 mm.) in length. The specimens which were found in the Gault[1] measured about $\frac{1}{35}$ inch (0·75 mm.), whilst Dr. Brady's measurements of the same species are $\frac{1}{25}$ to $\frac{1}{6}$ inch (1 to 4 mm.) in length.

Four specimens from Bargate Pebble-beds, Littleton.

TRITAXIA, Reuss.

25. TRITAXIA TRICARINATA, Reuss.

Tr. tricarinata, Reuss, 'Verstein. böhm. Kreid.' pt. i. (1845) p. 39, pl. viii. fig. 60; Reuss, Sitzungsb. Akad. Wiss. Wien, vol. xl. (1860) p. 228, pl. xii. figs. 1, 2; Chapman, Journ. Roy. Micr. Soc. 1892, p. 749, pl. xi. fig. 1.

This species, like the preceding, is characteristic of Cretaceous

[1] Chapman, Journ. Roy. Micr. Soc. 1892, p. 329, pl. vi. fig. 24 *a*, *b*.

strata. The Bargate specimens resemble those from the Gault in that they possess an inflated terminal chamber, probably indicative of age.

From Bargate Pebble-beds, Littleton (two specimens); and from Halfpenny Lane, Chilworth (one).

Spiroplecta, Ehrenberg.

26. Spiroplecta annectens (Parker & Jones).

Textularia annectens, Parker & Jones, Ann. & Mag. Nat. Hist. ser. 3, vol. xi. (1863) p. 92, woodcut, fig. 1.

Spiroplecta annectens, Brady, 'Challenger' Rep. vol. ix. (1884) p. 376, pl. xlv. figs. 22, 23.

Some minute specimens of the above species, which is not uncommon in the Gault, occur in the Bargate series.

Two specimens from clay of Pebble-beds, Littleton; and one from clay of Bargate Beds, Holloway Hill.

27. Spiroplecta biformis (Parker & Jones).

Textularia agglutinans, var. *biformis*, Parker & Jones, Phil. Trans. Roy. Soc. vol. clv. (1865) p. 370, pl. xv. figs. 23, 24.

Spiroplecta biformis, Brady, 'Challenger' Rep. vol. ix. (1884) p. 376, pl. xlv. figs. 25–27.

The specimens of the above species from the Bargate series are quite typical, having a coarsely arenaceous test, inflated chambers, and rounded edges to the test. It is known from Upper Cretaceous strata, etc.

Two specimens from Pebble-beds, Littleton; two from clay of Bargate Beds, Holloway Hill; and five from beds below Folkestone series, Horsham Road, Dorking.

Gaudryina, d'Orbigny.

28. Gaudryina pupoides, d'Orbigny.

G. pupoides, d'Orbigny, Mém. Soc. géol. France, vol. iv. (1840) p. 44, pl. iv. figs. 22–24.

This species is frequent in Cretaceous strata.

Six typical examples were found in the Bargate series in the Pebble-beds at Littleton, and two in the Bargate Beds at Holloway Hill.

29. Gaudryina baccata, Schwager.

G. baccata, Schwager, 'Novara' Exped., geol. Theil, vol. ii. (1866) p. 200, pl. iv. fig. 12.

Three specimens from Bargate Beds, Holloway Hill, Godalming.

30. Gaudryina filiformis, Berthelin.

G. filiformis, Berthelin, Mém. Soc. géol. France, sér. 3, vol. i. (1880) no. 5, p. 25, pl. i. fig. 8.

This form was first described from the Gault of France, and has subsequently been found in the English Gault.

One specimen from clay of Bargate Pebble-beds, Littleton.

Valvulina, d'Orbigny.

31. Valvulina conica, Parker & Jones.

V. triangularis, var. *conica*, Parker & Jones, Phil. Trans. Roy. Soc. vol. clv. (1865) p. 406, pl. xv. fig. 27.

V. conica, Brady, 'Challenger' Rep. vol. ix. (1884) p. 392, pl. xlix. figs. 15, 16.

This species has been recorded from the Gault, and is also found living at the present time.

One specimen from Bargate Beds, Holloway Hill.

32. Valvulina fusca (Williamson).

Rotalina fusca, Williamson, 'Rec. For. Gt. Br.' 1858, p. 55, pl. v. figs. 114, 115.

Valvulina fusca, Brady, 'Challenger' Rep. vol. ix. (1884) p. 392, pl. xlix. figs. 13, 14.

V. fusca has been found in the Gault, otherwise, like the preceding species, it was known only from recent gatherings.

Three specimens from Bargate Pebble-beds, Littleton; they are not attached, but they plainly show their adherent character.

Bulimina, d'Orbigny.

33. Bulimina polystropha, Reuss. (Pl. XXXIV. fig. 5.)

B. polystropha, Reuss, 'Verstein. böhm. Kreid.' pt. ii. (1845) p. 109, pl. xxiv. fig. 53 *a*, *b*.

This species is perhaps one of the most interesting and important of the foraminifera found in the Bargate series, since it throws some light on the actual position of the specimens found by Reuss in the Chalk of Bohemia. The Bargate specimens are somewhat coarsely arenaceous, with a rough surface, triserial, and they have the aboral end distinctly twisted as in Reuss's figure; moreover, the aperture is clearly that of a *Bulimina*, being comma-shaped. The figure given by Reuss (*loc. cit.*) is misleading, since the surface of the test is depicted as being smooth, although in the description of the species it is stated to be rough. The form referred to in the Monographs of the Gault Foraminifera of Montcley[1] and Folkestone[2] as *Bulimina polystropha*, Rss., I am now inclined

[1] Berthelin, Mém. Soc. géol. France, sér. 3, vol. i. (1880) no. 5, p. 30, pl. ii. fig. 3 *a*, *b*.

[2] Chapman, Journ. Roy. Micr. Soc. 1892, p. 756, pl. xii. fig. 11.

to refer to *Verneuilina pygmæa*, Egger, sp., the latter being a form which has the test of fine arenaceous material, quite hyaline in appearance, and with a Textularian aperture. It is worth noting that an isomorphous and recent form which Dr. Brady connects with Reuss's species, but which, because of the Textularian aperture, is placed in the genus *Verneuilina*, lives in shallow water to the depth of 50 fathoms, its place being apparently occupied below that depth by the larger and stronger variety *Verneuilina propinqua*, Brady.

The Bargate specimens of *Bulimina polystropha* measure from $\frac{1}{60}$ to $\frac{1}{45}$ inch (0·42 to 0·56 mm.) in length, while Dr. Brady's specimens were $\frac{1}{40}$ inch (0·63 mm.) long.

One specimen from siliceous residue of Bargate limestone, Littleton; three from clay in Pebble-beds, Littleton; one from Bargate Beds, Holloway Hill; and one from beds below Folkestone series, Horsham Road, Dorking.

34. Bulimina pupoides, d'Orbigny.

B. pupoides, d'Orbigny, 'Foram. Foss. Vienne,' 1846, p. 185, pl. xi. figs. 11, 12; Brady, 'Challenger' Rep. vol. ix. (1884) p. 400, pl. l. fig. 15 *a*, *b*.

Five specimens from Pebble-beds, Littleton; and one from beds below Folkestone series, Horsham Road, Dorking.

35. Bulimina affinis, d'Orbigny.

B. affinis, d'Orbigny, 'Foram. Cuba,' 1839, p. 109, pl. ii. figs. 25, 26.

Five typically formed, but small, examples were found in the Pebble-beds, Littleton; and two in the Bargate Beds, Holloway Hill.

36. Bulimina ovata, d'Orbigny.

B. ovata, d'Orbigny, 'Foram. Foss. Vienne,' 1846, p. 185, pl. xi. figs. 13, 14.

Three specimens from Pebble-beds, Littleton; and one from Bargate Beds, Holloway Hill.

37. Bulimina pyrula, d'Orbigny.

B. caudigera, d'Orbigny, Ann. Sci. Nat. vol. vii. (1826), p. 270, no. 16: Modèle no. 68.

B. pyrula, d'Orbigny, 'Foram. Foss. Vienne,' 1846, p. 184, pl. xi. figs. 9, 10.

The occurrence of this species in the Bargate Beds is interesting, since it has been before recorded by Messrs. Parker and Jones from beds (probably Liassic) at Chellaston, and it also occurs in the Gault.

One specimen from siliceous residue of Bargate limestone, Littleton; and five from Pebble-beds, Littleton.

38. Bulimina obliqua, d'Orbigny.

B. obliqua, d'Orbigny, Mém. Soc. géol. France, vol. iv. (1840)

p. 40, pl. iv. figs. 7, 8; Chapman, Journ. Roy. Micr. Soc. 1892, p. 754, pl. xii. fig. 3.

The specimens from the Bargate Beds closely resemble the Gault specimens.

One specimen from siliceous residue of Bargate limestone, Littleton; two from Bargate Pebble-beds, Littleton; one from Pebble-beds, Halfpenny Lane; and one from Bargate Beds, Holloway Hill.

39. Bulimina Presli, Reuss.

B. Presli, Reuss, 'Verstein. böhm. Kreid.' pt. i. (1845) p. 38, pl. xiii. fig. 72.

This species is the largest of the *Buliminæ* from the Bargate series, the specimens measuring $\frac{1}{40}$ inch (0·63 mm.) in length. This form is also found in the Gault of Folkestone (where it attains the same size) and in other Cretaceous strata.

Two specimens from Bargate Pebble-beds, Littleton.

40. Bulimina obtusa, d'Orbigny.

B. obtusa, d'Orbigny, Mém. Soc. géol. France, vol. iv. (1840) p. 39, pl. iv. figs. 5, 6.

This species, which is already known from the Gault and Chalk, was found in the Pebble-beds, Littleton (three specimens); in the siliceous residue of the Bargate Stone, Halfpenny Lane, Chilworth (one); and in the Bargate Beds, Holloway Hill (one).

41. Bulimina Murchisoniana, d'Orbigny.

B. Murchisoniana, d'Orbigny, Mém. Soc. géol. France, vol. iv. (1840) p. 41, pl. iv. figs. 15, 16.

Two specimens from the Pebble-beds, Littleton.

42. Bulimina brevis, d'Orbigny.

B. brevis, d'Orbigny, Mém. Soc. géol. France, vol. iv. (1840) p. 41, pl. iv. figs. 13, 14.

This species was previously known as peculiar to Cretaceous strata, occurring in the Gault and Chalk.

Nine specimens from Bargate Pebble-beds, Littleton; one from Pebble-beds, Halfpenny Lane; one from Bargate Beds, Holloway Hill; and two from beds below Folkestone series, Horsham Road, Dorking.

Virgulina, d'Orbigny.

43. Virgulina subsquamosa, Egger.

V. subsquamosa, Egger, Neues Jahrb. 1857, p. 295, pl. xii. figs. 19–21.

Previously recorded from Miocene and later deposits, this form occurs in the Bargate Pebble-beds, Littleton (three specimens); and in the Bargate Beds, Holloway Hill (one).

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[illegible]

Bargate Beds are not quite typical, but the difference is so slight that it appears to be worth no varietal distinction. In *Ehrenbergina pupa* the conformation of the test can be compared with a *Bulimina* which has been flattened or stretched out in its widest direction, the two lateral margins folded together, and the test coiled vertically upon itself. The Bargate specimens exhibit the longitudinal folding, but not to so marked an extent as in recent examples. The species has not been before recorded in the fossil condition.

Three specimens from the Pebble-beds, Littleton.

Family LAGENIDÆ.

Subfamily Lageninæ.

Lagena, Walker & Boys.

49. Lagena globosa (Montagu).

Vermiculum globosum, Montagu, 'Test. Brit.' 1803, p. 523.

Entosolenia globosa, Parker & Jones, Ann. & Mag. Nat. Hist. ser. 2, vol. xix. (1857) p. 278, pl. xi. figs. 25–29.

Lagena globosa, Brady, 'Challenger' Rep. vol. ix. (1884) p. 452, pl. lvi. figs. 1–3.

L. globosa is known from beds of Jurassic age upwards. It is represented in the present series by six specimens, one of which is pyriform, whilst the remaining five are subglobular. Four were found in the Pebble-beds, Littleton, one (silicified) in the siliceous residue of Bargate limestone from Halfpenny Lane, and one in the Pebble-beds, same locality.

50. Lagena apiculata, Reuss.

Oolina apiculata, Reuss, Haidinger's Naturw. Abhandl. vol. iv. (1850) p. 22, pl. i. fig. 1.

Lagena apiculata, Reuss, Sitzungsb. Akad. Wissensch. Wien, vol. xlvi. (1862) p. 319, pl. i. figs. 4–8, 10, 11.

L. apiculata, Brady, 'Challenger' Rep. vol. ix. (1884) p. 453, pl. lvi. figs. 4, 15–18.

This species is known from the Lias and many fossiliferous beds of later date. It is common in the English Gault, and is also found in Cretaceous deposits of North Germany of about the same age.

The four specimens from the Pebble-beds, Littleton, are all subglobose in form.

51. Lagena lævis (Montagu).

Vermiculum læve, Montagu, 'Test. Brit.' 1803, p. 324.

Lagena lævis, Williamson, Ann. & Mag. Nat. Hist. ser. 2, vol. i. (1848) p. 12, pl. i. figs. 1, 2; Brady, 'Challenger' Rep. vol. ix. (1884) p. 455, pl. lvi. figs. 7–14, 30.

An example of this foraminifer was seen in a thin section of

[illegible]

56. Nodosaria (Dentalina) xiphioides, Reuss.

N. (*D.*) *xiphioides*, Reuss, Sitzungsb. Akad. Wissensch. Wien, vol. xlvi. (1862) p. 43, pl. iii. fig. 1.

This species has been hitherto apparently restricted to the Gault formation, since it was found in the *Minimus*-Thon of North Germany, in the Gault of Montcley, and at Folkestone.

One specimen with three chambers, from the Pebble-beds, Littleton.

57. Nodosaria (Dentalina) limbata, d'Orbigny.

N. limbata, d'Orbigny, Mém. Soc. géol. France, vol. iv. (1840) p. 12, pl. i. fig. 1.

N. limbata is a characteristic Chalk fossil, and has also been found in the Red Chalk of Hunstanton.[1]

The three fragmentary examples found in the Pebble-beds at Littleton are not quite so deeply constricted between the chambers as in the figures given by d'Orbigny, but they exhibit the test-thickening between the segments.

58. Nodosaria (Dentalina) Fontannesi, Berthelin.

Dentalina Fontannesi, Berthelin, Mém. Soc. géol. France, sér. 3, vol. i. (1880) no. 5, p. 42, pl. ii. fig. 14.

This form has been described from the French and English Gault.

Two specimens from the Pebble-beds, Littleton.

59. Nodosaria (Dentalina) obscura, Reuss.

N. obscura, Reuss, 'Verstein. böhm. Kreid.' pt. i. (1845) p. 26, pl. xiii. figs. 7–9.

A familiar Cretaceous species, two specimens of which, differing greatly in size (and the larger one fragmentary), were found in the Bargate Pebble-beds at Littleton.

60. Nodosaria tenuicosta, Reuss.

N. tenuicosta, Reuss, 'Verstein. böhm. Kreid.' pt. i. (1845) p. 25, pl. xiii. figs. 5, 6.

A Cretaceous form between *N. raphanus* (Linn.) and *N. raphanistrum* (Linn.), with thin platy costæ. It has been found in beds equivalent in age to the Lower Greensand in Germany, also in the French and English Gault, and in the Pläner-Mergel of Bohemia.

Two specimens from Pebble-beds, Littleton.

61. Nodosaria prismatica, Reuss.

N. prismatica, Reuss, Sitzungsb. Akad. Wissensch. Wien, vol. xl. (1860) p. 180, pl. ii. fig. 2.

N. prismatica is already known from beds of Lower Greensand

[1] Burrows, Sherborn, & Bailey, Journ. Roy. Micr. oc. 1890, p. 557, pl. ix. fig. 23.

age in North Germany, from the Gault, and other later Cretaceous deposits.

One fragmentary specimen from Pebble-beds, Halfpenny Lane, below St. Martha's Chapel, Chilworth.

LINGULINA, d'Orbigny.

62. LINGULINA CARINATA, d'Orbigny.

L. carinata, d'Orbigny, Ann. Sci. Nat. vol. vii. (1826) p. 257, no. 1 : Modèle no. 26.

This species has been recorded from various fossiliferous deposits, including the Lias, and many Cretaceous and Tertiary beds.

The form figured from the Red Chalk of Hunstanton [1] appears to be a variety intermediate between *L. carinata*, d'Orbigny, and *L. nodosaria*, Reuss, and would therefore be represented by the form *L. bohemica*, Reuss.

L. carinata from the Bargate series resembles the figures of recent specimens in that they have a short and rather broad (ovate) test, tending to become acuminate at the aboral end, with sharp sides, and low and numerous chambers.

Three specimens from the Pebble-beds, Littleton.

63. LINGULINA SEMIORNATA, Reuss.

L. semiornata, Reuss, Sitzungsb. Akad. Wissensch. Wien, vol. xlvi. (1862) p. 91, pl. xii. fig. 11.

The above species was described by Reuss from the Folkestone Gault, and it is well distributed through that formation ; moreover, it appears to be almost entirely restricted to those beds, since its only occurrence out of the Gault (besides the present record), so far as I am aware, has been noticed by myself, whilst examining some Chalk-marl from East Wear Bay, Folkestone, for a comparative study of the Cretaceous rhizopoda. The specimens from the Bargate series are slightly worn on their surfaces, but the semistriate character of the test is distinctly seen when moistened.

Two specimens from the Pebble-beds, Littleton.

64. LINGULINA SEMIORNATA, Reuss, var. CRASSA, nov. (Pl. XXXIV. fig. 8 *a*, *b*.)

Associated with the specimens of *L. semiornata* from the Bargate Pebble-bed, was a *Lingulina* singularly distinct from the typical form with a fragile and slender test, since it possesses a heavily-made test, and much broader than that of the type form. The semistriate character is also present in this example. The length of the test is $\frac{1}{33}$ inch (0·75 mm.), the breadth $\frac{1}{85}$ inch (0·3 mm.)

One specimen from the Pebble-beds, Littleton.

[1] Burrows, Sherborn, & Bailey, Journ. Roy. Micr. Soc. 1890, p. 558, pl. x. fig. 3 *a*, *b*.

FRONDICULARIA, Defrance.

65. FRONDICULARIA BRIZÆFORMIS, Bornemann. (Pl. XXXIV. fig. 9 *a*, *b*).

F. brizæformis, Bornemann, 'Liasformation von Göttingen,' 1854, p. 36, pl. iii. figs. 17 *a–d*, 18 *a–c*, 20 *a*, *b*.

A perfect example of this very elegant Liassic species was found in the Bargate Pebble-beds at Littleton. The Lower Greensand specimen is much neater than those figured by Bornemann (*loc. cit.*).

MARGINULINA, d'Orbigny.

66. MARGINULINA LINEARIS, Reuss.

M. linearis, Reuss, Sitzungsb. Akad. Wissensch. Wien, vol. xlvi. (1862) p. 60, pl. v. fig. 15.

M. linearis has been found in the *Minimus*-Thon of North Germany, and in the Gault of Folkestone.

One specimen from the Pebble-beds, Littleton.

67. MARGINULINA DEBILIS, Berthelin.

M. debilis, Berthelin, Mém. Soc. géol. France, sér. 3, vol. i. (1880) no. 5, p. 35, pl. iii. fig. 28.

One fragmentary specimen of this Gault species, from the Pebble-beds, Littleton.

68. MARGINULINA COMPRESSA, d'Orbigny.

M. compressa, d'Orbigny, Mém. Soc. géol. France, vol. iv. (1840) p. 17, pl. i. figs. 18, 19; Reuss, 'Verstein. böhm. Kreid.' pt. i. (1845) p. 29, pl. xiii. fig. 33.

One example of this Upper Cretaceous species, from the Pebble-beds, Littleton.

69. MARGINULINA ÆQUIVOCA, Reuss.

M. æquivoca, Reuss, Sitzungsb. Akad. Wissensch. Wien, vol. xlvi. (1862) p. 60, pl. v. fig. 17.

One specimen of this form, previously recorded from the *Minimus*-Thon of North Germany and from the French and English Gault, was found in the Pebble-beds, Littleton.

70. MARGINULINA JONESI, Reuss.

M. Jonesi, Reuss, Sitzungsb. Akad. Wissensch. Wien, vol. xlvi. (1862) p. 61, pl. v. fig. 19.

This species has previously been recorded from beds of Neocomian age (Upper Hils-Thon) of North Germany, and from the Gault of France and England.

One specimen from the Pebble-beds, Littleton, and three in the Pebble-beds at Halfpenny Lane, below St. Martha's Chapel, Chilworth.

71. Marginulina striatocostata, Reuss.

M. striatocostata, Reuss, Sitzungsb. Akad. Wissensch. Wien, vol. xlvi. (1862) p. 62, pl. vi. fig. 2.

Two specimens of a *Marginulina*, with well-rounded aboral ends, occurred in the Pebble-beds, Littleton, and must be referred to the above species. *M. striatocostata* has been found in the Upper Hils formation near Brunswick.

72. Marginulina Munieri, Berthelin.

M. Munieri, Berthelin, Mém. Soc. géol. France, sér. 3, vol. i. (1880) no. 5, p. 33, pl. i. figs. 19 *a*, *b*.

This species has been described from the French Gault, and it is also found at Folkestone.

Two specimens from the Pebble-beds, Littleton.

Vaginulina, d'Orbigny.

73. Vaginulina legumen (Linné).

Nautilus legumen, Linné, 'Syst. Nat.' 10th ed. (1758) p. 711, no. 248; 12th ed. (1767) p. 1164, no. 288.

Vaginulina legumen, Brady, 'Challenger' Rep. vol. ix. (1884) p. 530, pl. lxvi. figs. 13–15.

This species makes its first appearance in beds of Liassic age, and is also generally distributed through nearly all later fossiliferous deposits.

Two specimens from the Pebble-beds, Littleton.

74. Vaginulina arguta, Reuss.

V. arguta, Reuss, Sitzungsb. Akad. Wissensch. Wien, vol. xl. (1860) p. 202, pl. viii. fig. 4; vol. xlvi. (1862) p. 47, pl. iii. fig. 13.

This species is known from the Gault and Neocomian beds of North Germany, and from the Gault of England and France.

One specimen from the Pebble-beds, Littleton.

75. Vaginulina sparsicostata, Reuss.

V. sparsicostata, Reuss, Sitzungsb. Akad. Wissensch. Wien, vol. xlvi. (1862) p. 50, pl. iv. fig. 4.

This species was found by Reuss in the Upper Hils-Thon of North Germany.

The Bargate specimens are both damaged, and the more perfect one agrees with Reuss's figure, with the exception that the latter has the primordial chamber quite minute, whilst in the former it is large and inflated. This difference may, however, be referred to a 'dimorphic' relation between the two examples of the same species, Reuss's specimen belonging to form B, whilst the Bargate specimen exemplifies form A of MM. Munier-Chalmas and Schlumberger.[1]

Two fragmentary specimens from the Pebble-beds, Littleton.

[1] Comptes-rendus Acad. Sci. Paris, vol. xcvi. (1883) pp. 862, 1598; Ann. & Mag. Nat. Hist. ser. 5, vol. xi. (1883) p. 336, & vol. xii. (1883) p. 67.

76. VAGINULINA NEOCOMIANA, sp. nov. (Pl. XXXIV. figs. 10 *a*, *b*, 11.)

Test elongate; slightly incurved in the first third of the test, and recurved from a third above the commencement to the terminal chamber. Segments numerous (eight in the full-grown individual); the primordial chamber circular and more or less inflated, following which the chambers are compressed and typically Vaginuline; but later on they assume the character of Marginuline segments, since they are subtriangular in section, and terminate in a marginal neck. Towards the back of the test on each side is a marginal keel, whilst the back itself is also sharp. Sutures well marked, especially in the larger and well-grown examples, which have the later chambers tending to separate one from the other. Surface of the test longitudinally striated with fine costæ. Length of largest specimen $\frac{1}{28}$ inch (0·9 mm.).[1]

Seven specimens, some fragmentary, from the Pebble-beds, Littleton.

CRISTELLARIA, Lamarck.

77. CRISTELLARIA TRICARINELLA, Reuss.

C. tricarinella, Reuss, Sitzungsb. Akad. Wissensch. Wien, vol. xlvi. (1862) p. 68, pl. vii. fig. 9.

C. truncana, Gümbel, Abhandl. bayer. Akad. Wissensch. 2te Cl. vol. x. (1868) p. 639, pl. i. fig. 68 *a*, *b*.

C. tricarinella, Brady, 'Challenger' Rep. vol. ix. (1884) p. 540, pl. lxviii. figs. 3, 4.

C. tricarinella is somewhat closely related to certain forms of *Vaginulina*, but although the sides of the test are nearly flat, it commences with a distinct spiral growth. Reuss records this species from the Hils-Thon and Speeton Clay of North Germany, and Gümbel obtained his specimens from the Nummulitic marl of the Kressenberg, Bavaria. Its occurrence as a recent form is noted by Dr. Brady from the Pacific, at depths of from 95–155 fathoms.

One specimen from the Pebble-beds, Littleton, and one from the Pebble-beds, Halfpenny Lane, Chilworth.

78. CRISTELLARIA VESTITA, Berthelin.

C. vestita, Berthelin, Mém. Soc. géol. France, sér. 3, vol. i. (1880) no. 5, p. 55, pl. iii. fig. 22.

This pretty costate form is allied to *C. italica* (Defrance) in outline, but differs in the ornamentation of the test. It was described from the Gault of France, and is also known from Folkestone.[2]

Two specimens from the Pebble-beds, Littleton.

[1] Several of Terquem's Jurassic species are somewhat related to this form, especially *Marginulina hybrida* ('Foram. du Lias,' 5me Mém., Metz, 1866, p. 430, pl. xvii. figs. 9 *a*, *b*, *c*), except that the latter has a Cristellarian commencement. Also *Vaginulina linearis* (Montagu) resembles the above form, but differs materially in having no extreme form of Marginuline neck.

[2] Author's MS.

79. Cristellaria italica (Defrance).

Saracenaria italica, Defrance, Dict. Sci. Nat. vol. xxxii. (1824) p. 177, vol. xlvii. p. 344; Atlas Conch. pl. xiii. fig. 6.

Cristellaria (*Saracenaria*) *italica*, d'Orbigny, Ann. Sci. Nat. vol. vii. (1826) p. 293, no. 26: Modèles nos. 19 & 85.

C. italica, Brady, 'Challenger' Rep. vol. ix. (1884) p. 544, pl. lxviii. figs. 17, 18, 20–23.

This form is known from Upper Cretaceous and Tertiary strata, and as a recent form it is never found in very deep water.

One specimen from the Pebble-beds, Littleton.

80. Cristellaria sulcifera, Reuss.

C. sulcifera, Reuss, Sitzungsb. Akad. Wissensch. Wien, vol. xlvi. (1862) p. 74, pl. viii. fig. 9.

Previously known from the *Minimus*-Thon of North Germany and from the Gault at Folkestone (Reuss); three specimens were found in the Bargate Pebble-beds, Littleton.

81. Cristellaria complanata, Reuss.

C. complanata, Reuss, 'Verstein. böhm. Kreid.' pt. i. (1845) p. 33, pl. xiii. fig. 54; Reuss, Sitzungsb. Akad. Wissensch. Wien, vol. xlvi. (1862) p. 92, pl. xii. fig. 13.

This species has been recorded from the Chalk of Bohemia, and from the Gault of Folkestone and Montcley.

One specimen from the Pebble-beds, Littleton.

82. Cristellaria parallela, Reuss.

C. parallela, Reuss, Sitzungsb. Akad. Wissensch. Wien, vol. xlvi. (1862) p. 67, pl. vii. figs. 1, 2.

This species is known from the Upper Hils-Thon of North Germany and from the Gault of France.

One specimen from the Pebble-beds, Littleton.

83. Cristellaria Schloenbachi, Reuss.

C. Schloenbachi, Reuss, Sitzungsb. Akad. Wissensch. Wien, vol. xlvi. (1862) p. 65, pl. vi. figs. 14, 15.

This species was described by Reuss from the Upper Hils-Thon and Specton Clay of North Germany. Dr. Brady records it from deep-sea deposits at depths varying from 155 to 435 fathoms.

Two specimens from the Pebble-beds, Littleton, and one from the Pebble-beds, Halfpenny Lane, near St. Martha's Chapel, Chilworth.

84. Cristellaria crepidula (Fichtel & Moll).

Nautilus crepidula, F. & M., 'Test. Micr.' 1803, p. 107, pl. xix. figs. *g–i*.

Cristellaria crepidula, d'Orbigny, 'Foram. Cuba,' 1839, p. 64, pl. viii. figs. 17, 18; Brady, 'Challenger' Rep. vol. ix. (1884) p. 542, pl. lxvii. figs. 17, 19, 20, pl. lxviii. figs. 1, 2.

This species has been obtained from beds as old as the Lias, and

it occurs in nearly all subsequently formed fossiliferous deposits, as well as in those of the present time. The recent forms are found in shallow, to moderately deep, waters.

Four typical specimens from the Pebble-beds, Littleton.

85. Cristellaria grata, Reuss.

C. grata, Reuss, Sitzungsb. Akad. Wissensch. Wien, vol. xlvi. (1862) p. 70, pl. vii. fig. 4.

This form was originally described from the Neocomian beds of North Germany.

One specimen from the Pebble-beds, Littleton.

86. Cristellaria cymboides, d'Orbigny.

C. cymboides, d'Orbigny, 'Foram. Foss. Vienne,' 1846, p. 85, pl. iii. figs. 30, 31.

One very fine and perfect example of this Tertiary species was found in the Bargate Pebble-beds, Littleton.

87. Cristellaria lævigata, Reuss.

C. lævigata, Reuss, Sitzungsb. Akad. Wissensch. Wien, vol. xlvi. (1862) p. 92, pl. xii. fig. 14.

Reuss described this species from the Gault at Folkestone.

Three specimens from the Pebble-beds, Littleton.

88. Cristellaria acutauricularis (Fichtel & Moll).

Nautilus acutauricularis, F. & M., 'Test. Micr.' 1803, p. 102, pl. xviii. figs. *g–i*.

C. acutauricularis, Brady, 'Challenger' Rep. vol. ix. (1884) p. 543, pl. cxiv. fig. 17 *a*, *b*.

Five specimens of this form, which occurs in various Secondary and Tertiary deposits, were found in the Pebble-beds, Littleton.

89. Cristellaria Bronni (Römer).

Planularia Bronni, Römer, 'Verstein. nordd. Kreidegeb.' 1840–41, p. 97, pl. xv. fig. 14.

Cristellaria Bronni, Reuss, Sitzungsb. Akad. Wissensch. Wien, vol. xlvi. (1862) p. 70, pl. vii. fig. 13.

This species has been found in the Speeton Clay of North Germany.

One specimen from the Pebble-beds, Littleton, and one from the Pebble-beds, Halfpenny Lane, Chilworth.

90. Cristellaria oligostegia, Reuss.

C. oligostegia, Reuss, Sitzungsb. Akad. Wissensch. Wien, vol. xl. (1860) p. 213, pl. viii. fig. 8; and vol. xlvi. (1862) p. 93, pl. xiii. fig. 2.

This species was found by Reuss in the detrital sand of the Westphalian Chalk, and also in the Gault of Folkestone.

One young specimen from the Pebble-beds, Halfpenny Lane, Chilworth.

91. Cristellaria rotulata (Lamarck).

Lenticulites rotulata, Lamarck, Ann. Muséum, vol. v. (1804) p. 188, no. 3; Tab. Encycl. Méth. pl. ccccixvi. fig. 5.

Cristellaria rotulata, Brady, 'Challenger' Rep. vol. ix. (1884) p. 547, pl. lxix. fig. 13 *a*, *b*.

This species makes its first appearance in beds of Ordovician age (Ulrich), and is common in most fossiliferous deposits up to the present time. As a recent form it occurs in shallow-water deposits and also in those down to a depth of 2200 fathoms (Brady).

Twelve specimens from the Pebble-beds, Littleton, and two from the Pebble-beds, Halfpenny Lane.

92. Cristellaria cultrata (Montfort).

Robulus cultratus, Montfort, 'Conchyl. System.' vol. i. (1808) p. 214, 54e genre.

Cristellaria cultrata, Brady, 'Challenger' Rep. vol. ix. (1884) p. 550, pl. lxx. figs. 4–6.

This form is first met with in beds of Liassic age, and it is also fairly common in Cretaceous and Tertiary strata. As a recent organism it affects deeper water than the preceding species.

Nine specimens from the Pebble-beds, Littleton, and two from the Pebble-beds, Halfpenny Lane.

93. Cristellaria gibba, d'Orbigny.

C. gibba, d'Orbigny, 'Foram. Cuba,' 1839, p. 63, pl. vii. figs. 20, 21.

C. pulchella, Reuss, Sitzungsb. Akad. Wissensch. Wien, vol. xlvi. (1862) p. 71, pl. viii. fig. 1.

The fossil forms recorded by Reuss were from the Upper Hils-Thon and the *Minimus*-Thon of North Germany. As a recent form it is found in soundings down to 500 fathoms (Brady).

Eight specimens from the Pebble-beds, Littleton, and one from the Pebble-beds in Halfpenny Lane.

94. Cristellaria convergens, Bornemann.

C. convergens, Bornemann, Zeitschr. deutsch. geol. Gesellsch. vol. vii. (1855) p. 327, pl. xiii. figs. 16, 17.

As a fossil the above species has been recorded from Tertiary strata. It is also found as a recent form, usually in deep water.

Two specimens from the Pebble-beds, Littleton.

95. Cristellaria prominula, Reuss.

C. prominula, Reuss, Zeitschr. deutsch. geol. Gesellsch. vol. vii. (1855) p. 271, pl. ix. fig. 3 *a*, *b*.

One specimen of this Cretaceous species was found in the Pebble-beds, Littleton.

96. Cristellaria megalopolitana (Reuss).

Robulina megalopolitana, Reuss, Zeitschr. deutsch. geol. Gesellsch. vol. vii. (1855) p. 272, pl. ix. fig. 5 *a*, *b*.

C. subalata, Reuss, Sitzungsb. Akad. Wissensch. Wien, vol. xlvi. (1862) pp. 76 & 93, pl. viii. fig. 10, pl. ix. fig. 1.

C. megalopolitana, Sherborn & Chapman, Journ. Roy. Micr. Soc. ser. 2, vol. vi. (1886) p. 755, pl. xv. fig. 30 *a*, *b*.

This form has been found in Neocomian, Upper Cretaceous, and Tertiary strata. It is separated from the foregoing species by the inflation of the test, especially in the umbilical region, and by the perfect cristation of the peripheral edge. *C. subalata* was described by Reuss from the Speeton Clay and *Minimus*-Thon of North Germany, and from the Gault of Folkestone; it has also been found in the Gault of Montcley, France (Berthelin).

One specimen from the Pebble-beds, Littleton.

97. Cristellaria varians, Bornemann.

C. varians, Bornemann, 'Liasformation von Göttingen,' 1854, p. 41, pl. iv. figs. 32–34; Tate & Blake (1876), p. 466, pl. xvii. fig. 27; Crick & Sherborn, Journ. Northampt. Nat. Hist. Soc. vol. vi. (1891) p. 213, pl. i. fig. 30, & vol. vii. (1892) p. 70, pl. ii. figs. 15, 16.

Two specimens of this Liassic form were found in the Pebble-beds, Littleton.

Subfamily Polymorphininæ.

Polymorphina, d'Orbigny.

98. Polymorphina amygdaloides, Reuss.

P. amygdaloides, Reuss, Sitzungsb. Akad. Wissensch. Wien, vol. xviii. (1855) p. 250, pl. viii. fig. 84.

A very typical, though small, specimen of the above was found in the Pebble-beds, Littleton.

99. Polymorphina sororia, Reuss, var. cuspidata, Brady.

P. sororia, var. *cuspidata*, Brady, 'Challenger' Rep. vol. ix. (1884) p. 563, pl. lxxi. figs. 17–19, pl. lxxii. fig. 4.

This variety was found in recent soundings by Dr. Brady, from depths between 808 and 1443 fathoms.

One specimen from the Pebble-beds, Littleton.

100. Polymorphina gutta, d'Orbigny.

P. (*Pyrulina*) *gutta*, d'Orbigny, Ann. Sci. Nat. vol. vii. (1826) p. 267, no. 28, p. 12, figs. 5, 6: Modèle no. 30.

This form has been recorded under the name of *Pyrulina obtusa*, by Reuss,[1] from the Hils-Thon (Neocomian) of North Germany; and it is also met with in other fossiliferous deposits of later date.

Three specimens from the Pebble-beds, Littleton.

[1] Sitzungsb. Akad. Wissensch. Wien, vol. xlvi. pt. i. (1862) p. 79, pl. ix. fig. 9.

101. Polymorphina communis, d'Orbigny.

P. (*Guttulina*) *communis*, d'Orbigny, Ann. Sci. Nat. vol. vii. (1826) p. 226, no. 15, pl. xii. figs. 1–4: Modèle no. 62.

This shallow-water form is represented here by one specimen from the Pebble-beds, Littleton.

102. Polymorphina compressa, d'Orbigny.

P. compressa, d'Orbigny, 'Foram. Foss. Vienne,' 1846, p. 243, pl. xii. figs. 32–34.

This species is also a shallow-water form, and makes its earliest appearance as a fossil in the Lias of France and England.

Two specimens from the Pebble-beds, Littleton.

103. Polymorphina oblonga, Williamson.

P. lactea, var. *oblonga*, Williamson, 'Rec. For. Gr. Brit.' 1858, p. 71, pl. vi. figs. 149, 149 *a*.

This species is easily distinguished from *P. angusta*, Egger,[1] by its compressed outline in transverse section. The Bargate specimens resemble *P. angusta* in the paucity of the chambers and the well-marked segmentation; but, since their whole test is compressed, they more properly belong to Williamson's species. This is, moreover, the first recorded occurrence of the species as a fossil.

Two specimens from the Pebble-beds, Littleton.

104. Polymorphina rhabdogonioides, sp. nov. (Pl. XXXIV. fig. 12 *a*, *b*.)

Test subpyramidal and quadrifacial; bluntly pointed at the base and rapidly increasing in width towards the oral extremity. The test is smooth, and consists of a Polymorphine series of chambers (slightly twisted as regards the commencement), the margins of which are deeply sunken, and the chambers themselves, numbering about five to seven on each face of the test, well inflated, especially in the case of the more or less central one visible on each face. The terminal chamber is large and embracing, subquadrangular in section, but not regular. The aperture is circular, and with the margin pectinate. Length $\frac{1}{70}$ inch (0·36 mm.); width diagonally $\frac{1}{110}$ inch (0·23 mm.).

The foregoing species is probably a dimorphous form, combining *Polymorphina* with *Rhabdogonium*, and, in the event of other varieties becoming known, it may be found necessary to form a distinct genus for this type.

Two specimens from the Pebble-beds, Littleton.

105. Polymorphina frondicularioides, sp. nov. (Pl. XXXIV. fig. 13 *a*, *b*.)

Test subpyriform, but somewhat compressed, tapering more acutely towards the aboral extremity; test rhomboidal in section. Surface smooth, and swollen along the centre of each face. About

[1] Neues Jahrb. 1857, p. 290, pl. xiii. figs. 13–15.

six chambers are visible on each surface, slightly inflated, and bordered by well-marked sutures. The last chamber is pinched up towards the apex; but it embraces the whole width of the test, after the manner of *Frondicularia* and *Lingulina*. Aperture slightly elongate, with a stellate border. Length $\frac{1}{68}$ inch (0·37 mm.); width $\frac{1}{130}$ inch (0·19 mm.).

This form also appears to represent a new genus or subgenus, combining two hitherto distinct generic types.

One specimen from the Pebble-beds, Littleton.

106. Polymorphina regina, Brady, Parker, & Jones.

P. regina, B., P., & J., Trans. Linn. Soc. Lond. vol. xxvii. (1870) p. 241, pl. xli. figs. 32 *a*, *b*.

A somewhat imperfect specimen and having a compressed test, but otherwise referable to this species, was found in the Bargate Beds, Holloway Hill.

107. Polymorphina concava, Williamson, var. dentimarginata, nov. (Pl. XXXIV. fig. 14 *a*, *b*.)

Test adherent, flat on the attached and convex on the opposite face. Subovate in outline, and sharply pointed at both ends. On the upper and lower surfaces, in the central area of the test, is exhibited a regular Polymorphine series, consisting of five chambers on the upper surface, and surrounding this is a secondary or later growth of shell-material, depauperate and thin, which appears to turn back upon the under surface, forming the adherent portion. The thin, outer, flange-like portion of the test shows the septation of five flattened segments. The delicate margin of the test is broken up into a fine pectinate edge; and, by careful observation, the surface is seen to be studded sparsely with minute prickles. Length $\frac{1}{37}$ inch (0·65 mm.); width $\frac{1}{85}$ inch (0·3 mm.).

The type form *P. concava*[1] has the attached or lower surface concave, and the margin of the test entire or simply waved; the lower surface would of course be conformable in shape to the object upon which it grew, so that concavity of surface is no true distinctive character in this species.

One specimen from the Pebble-beds, Littleton.

Subfamily Ramulininæ.

Ramulina, Jones.

108. Ramulina globulifera, Brady.

R. globulifera, Brady, Quart. Journ. Micr. Sci. n. s. vol. xix. (1869) p. 58, pl. viii. figs. 32, 33; id. 'Challenger' Rep. vol. ix. (1884) p. 587, pl. lxxvi. figs. 22–28.

It appears desirable to associate the smooth or prickly, tubular- and sometimes globular-chambered *Ramulina* of Cretaceous strata

[1] *Polymorphina lactea*, var. *concava*, Williamson, 'Rec. For. Gr. Brit.' 1858, p. 72, pl. vi. figs. 151, 152.

with the recent forms found in moderately deep water, and figured by Dr. Brady (*loc. cit.*), and to regard the *Dentalina aculeata* of d'Orbigny [1] as a true Nodosarian form.

A fragmentary specimen of the cylindrical portion of *R. globulifera* was found in the Pebble-beds, Littleton; and a similar one in the Pebble-beds in Halfpenny Lane, Chilworth.

Family GLOBIGERINIDÆ.

Globigerina, d'Orbigny.

109. Globigerina bulloides, d'Orbigny.

G. bulloides, d'Orbigny, Ann. Sci. Nat. vol. vii. (1826) p. 277, no. 1, Modèles nos. 17 and 76; Brady, 'Challenger' Rep. vol. ix. (1884) p. 593, pls. lxxvii., lxxix. figs. 3–7.

This species is met with in various Cretaceous and Tertiary beds, as well as in recent deposits.

The four specimens from the Bargate series are small, but are distinguishable from the more typical *G. cretacea* by the turbinoid form of the spire. Three come from the Pebble-beds, Littleton, and one from the Pebble-beds, Halfpenny Lane, Chilworth.

110. Globigerina cretacea, d'Orbigny.

G. cretacea, d'Orbigny, Mém. Soc. géol. France, vol. iv. (1840) p. 34, pl. iii. figs. 12–14.

This well-known and common Cretaceous species is represented in the Bargate series by three specimens, from the Pebble-beds, Littleton.

Family ROTALIIDÆ.

Subfamily Rotalinæ.

Patellina, Williamson.

111. Patellina corrugata, Williamson.

P. corrugata, Williamson, 'Rec. For. Gr. Brit.' 1858, p. 46, pl. iii. figs. 86–89.

This interesting little species has hitherto been found in the post-Tertiary beds of Scotland and Ireland, and, as a recent form, usually affects shallow water.

It is somewhat remarkable to find this small and delicate species in strata as old as the Neocomian, since the various species known from fossiliferous beds of Cretaceous and early Tertiary ages are of a stronger and larger build.

Five specimens from the Pebble-beds, Littleton; and two from the Bargate Beds, Holloway Hill.

112. Patellina antiqua, sp. nov. (Pl. XXXIII. fig. 12 *a*, *b*, *c*.)

Test nearly circular, superior face convex, and with about five

[1] Mém. Soc. géol. France, vol. iv. pt. i. (1840) p. 13, pl. i. figs. 2, 3.

whorls of semi-globular chambers arranged spirally; inferior face flat, the surface covered with papillæ arranged somewhat concentrically. Peripheral edge obtuse. Diameter of test $\frac{1}{80}$ inch (0·31 mm.); height $\frac{1}{250}$ inch (0·1 mm.).

One specimen from the Bargate Beds, Holloway Hill.

DISCORBINA, Parker & Jones.

113. DISCORBINA TURBO (d'Orbigny).

Rotalia (*Trochulina*) *turbo*, d'Orbigny, Ann. Sci. Nat. vol. vii. (1826) p. 274, no. 29: Modèle no. 73.

Discorbina turbo, Brady, 'Challenger' Rep. vol. ix. (1884) p. 642, pl. lxxxvii. fig. 8 *a*, *b*, *c*.

This species has previously been found in the Chalk of Maestricht and some strata of later age; and as a recent form it is found in shallow water, and deeper to 420 fathoms.

One specimen from the Pebble-beds, Littleton.

114. DISCORBINA ORBICULARIS (Terquem).

Rosalina orbicularis, Terquem, 'Anim. sur la Plage de Dunkerque,' 1876, p. 75, pl. ix. fig. 4 *a*, *b*.

Discorbina orbicularis, Brady, 'Challenger' Rep. vol. ix. (1884) p. 647, pl. lxxxviii. figs. 4–8.

Four specimens of this shallow-water form, which also occurs in Miocene and Pliocene strata, were found in the Pebble-beds, Littleton.

115. DISCORBINA PILEOLUS (d'Orbigny).

Valvulina pileolus, d'Orbigny, 'Foram. Amér. Mérid.' 1839, p. 47, pl. i. figs. 15–17.

Discorbina pileolus, Brady, 'Challenger' Rep. vol. ix. (1884) p. 649, pl. lxxxix. figs. 2–4.

D. pileolus has been found fossil in various Tertiary deposits. As a living form it affects shallow water down to 20 fathoms.

Two specimens from the Pebble-beds, Littleton.

116. DISCORBINA PARISIENSIS (d'Orbigny).

Rosalina parisiensis, d'Orbigny, Ann. Sci. Nat. vol. vii. (1826) p. 271, no. 1: Modèle no. 38.

Discorbina parisiensis, Brady, 'Challenger' Rep. vol. ix. (1884) p. 648, pl. xc. figs. 5, 6, 9–12.

This species is found in shallow water to a depth of 50 fathoms, and is recorded fossil from Tertiary strata.

Three specimens from the Pebble-beds, Littleton; and two from the Pebble-beds, Halfpenny Lane.

117. DISCORBINA ROSACEA (d'Orbigny).

Rotalia rosacea, d'Orbigny, Ann. Sci. Nat. vol. vii. (1826) p. 273, 15: Modèle no. 39.

Discorbina rosacea, Brady, 'Challenger' Rep. vol. ix. (1884) p. 644, pl. lxxxvii. figs. 1, 4.

This is also a shallow-water species, and it is found fossil in various Tertiary beds.

One specimen from the Pebble-beds, Littleton.

118. Discorbina Bertheloti (d'Orbigny).

Rosalina Bertheloti, d'Orbigny, 'Foram. Iles Canaries,' 1839, p. 135, pl. i. figs. 28–30.

Discorbina Bertheloti, Brady, 'Challenger' Rep. vol. ix. (1884) p. 650, pl. lxxxix. figs. 10–12.

This species is, in the recent condition, usually found at depths of less than 500 fathoms.

The forty-two Bargate specimens vary from $\frac{1}{170}$ inch (0·14 mm.) to $\frac{1}{60}$ inch (0·42 mm.) in diameter. They were found in the Pebble-beds, Littleton.

119. Discorbina Bertheloti, var. Baconica (Hantken).

D. Baconica, Hantken, Mittheil. Jahrb. ung. geol. Anstalt, vol. iv. (1875) p. 76, pl. x. fig. 3 *a*, *b*.

D. Bertheloti, var. *Baconica*, Brady, 'Challenger' Rep. vol. ix. (1884) p. 651, pl. xc. fig. 1 *a*, *b*, *c*.

This variety was described from the *Clavulina Szaboi*-beds (Tertiary) of Hungary, and as a recent form is known from depths of 600 to 1180 fathoms.

One specimen from the Pebble-beds, Littleton.

120. Discorbina concinna, Brady.

D. concinna, Brady, 'Challenger' Rep. vol. ix. (1884) p. 646, pl. xc. figs. 7, 8.

This species was recorded by Dr. Brady from depths of 15–620 fathoms.

Two specimens from the Pebble-beds, Littleton.

121. Discorbina rugosa (d'Orbigny).

Rosalina rugosa, d'Orbigny, 'Foram. Amér. Mérid.' 1839, p. 42, pl. ii. figs. 12–14.

Discorbina rugosa, Brady, 'Challenger' Rep. vol. ix. (1884) p. 652, pl. lxxxvii. fig. 3 *a*, *b*, *c*; pl. xci. fig. 4 *a*, *b*, *c*.

Seven specimens of this moderately shallow-water species were found in the Pebble-beds, Littleton.

122. Discorbina obtusa (d'Orbigny).

Rosalina obtusa, d'Orbigny, 'Foram. Foss. Vienne,' 1846, p. 179, pl. xi. figs. 4–6.

Discorbina obtusa, Brady, 'Challenger' Rep. vol. ix. (1884) p. 644, pl. xci. fig. 9 *a*, *b*, *c*?

This species is represented in the Bargate series by one typical specimen from the Pebble-beds, Halfpenny Lane, Chilworth.

123. Discorbina Vilardeboana (d'Orbigny).

Rosalina Vilardeboana, d'Orbigny, 'Foram. Amér. Mérid.' 1839, p. 44, pl. vi. figs. 13–15.

Discorbina Vilardeboana, Brady, 'Challenger' Rep. vol. ix. (1884) p. 645, pl. lxxxvi. figs. 9, 12; pl. lxxxviii. fig. 2.

One specimen of this shallow-water species was found in the Pebble-beds, Littleton.

124. Discorbina araucana (d'Orbigny).

Rosalina araucana, d'Orbigny, 'Foram. Amér. Mérid.' 1839, p. 44, pl. vi. figs. 16–18.

Discorbina araucana, Brady, 'Challenger' Rep. vol. ix. (1884) p. 645, pl. lxxxvi. figs. 10, 11.

Thirteen specimens of the above species, which is a shallow-water form, were found in the Pebble-beds, Littleton; and one in the Pebble-beds, Halfpenny Lane, Chilworth.[1]

Truncatulina, d'Orbigny.

125. Truncatulina lobatula (Walker & Jacob).

Nautilus lobatulus, Walker & Jacob, Adams's Essays, Kanmacher's ed. (1798) p. 642, pl. xiv. fig. 36.

Truncatulina lobatula, Brady, 'Challenger' Rep. vol. ix. (1884) p. 660, pl. xcii. fig. 10; pl. xciii. figs. 1, 4, 5; pl. cxv. figs. 4, 5.

Two specimens of this widely distributed species were found in the Pebble-beds, Littleton.

126. Truncatulina variabilis, d'Orbigny.

Truncatulina variabilis, d'Orbigny, Ann. Sci. Nat. vol. vii. (1826) p. 279, no. 8; Brady, 'Challenger' Rep. vol. ix. (1884) p. 661, pl. xciii. figs. 6, 7.

This form has been noted from the Chalk of Taplow, and from various Tertiary formations.

Four specimens from the Pebble-beds, Littleton.

127. Truncatulina falcata, Reuss. (Pl. XXXIV. fig. 15 *a*, *b*, *c*.)

Truncatulina falcata, Reuss, Sitzungsb. Akad. Wissensch. Wien, vol. lix. (1869) pt. i. p. 461, pl. ii. fig. 1.

This species was described by Reuss from the Oligocene Beds of Gaas in the South of France, in which deposit it appears to be very rare.

T. falcata is by far the most abundant species of foraminifera in the Bargate Beds of Surrey, and the specimens, moreover, agree very nearly with the original description of the test. There are, however, these unimportant differences between the Oligocene and the

[1] The specimens of *D. araucana*, and also some of *D. rugosa*, exhibit a tendency to become elongate in the plane of their discoidal growth, somewhat after the manner of *Truncatulina variabilis*.

Neocomian specimens, that in the latter the superior face is perfectly flat, whilst that of the Oligocene specimen was slightly inflated or convex. The species is easily recognized by the strongly developed central boss on the inferior face.

One hundred and fifty specimens of this species were found in the Pebble-beds, Littleton; twenty-three in the Pebble-beds, Halfpenny Lane; and one in the Bargate Beds, Holloway Hill.

128. Truncatulina Haidingerii (d'Orbigny).

Rotalina Haidingerii, d'Orbigny, 'Foram. Foss. Vienne,' 1846, p. 154, pl. vii. figs. 7–9.

Truncatulina Haidingerii, Brady, 'Challenger' Rep. vol. ix. (1884) p. 663, pl. xcv. fig. 7 *a–c*.

One specimen of this species, which occurs in tolerably deep water at the present day, and also as a Tertiary fossil, was found in the Pebble-beds in Halfpenny Lane.

129. Truncatulina Wuellerstorfi (Schwager).

Anomalina Wuellerstorfi, Schwager, 'Novara' Exped., geol. Theil, vol. ii. (1866) p. 258, pl. vii. figs. 105, 107.

Truncatulina Wuellerstorfi, Brady, 'Challenger' Rep. vol. ix. (1884) p. 662, pl. xciii. figs. 8, 9.

This species is characteristic of deep water as a recent form. It was originally described by Dr. Schwager from the Pliocene beds of Kar-Nicobar.

Twenty-three specimens from the Pebble-beds, Littleton; and one from the Pebble-beds, Halfpenny Lane.

Anomalina, d'Orbigny.

130. Anomalina ariminensis (d'Orbigny).

Planulina ariminensis, d'Orbigny, Ann. Sci. Nat. vol. vii. (1826) p. 280, pl. v. figs. 1–3 *bis*: Modèle no. 49.

Anomalina ariminensis, Brady, 'Challenger' Rep. vol. ix. (1884) p. 674, pl. xciii. figs. 10, 11.

This species has hitherto been found in the Chalk and Tertiary strata. As a recent form it is chiefly confined to shallow or moderately deep water. Two specimens were found in the Pebble-beds, Littleton.

131. Anomalina ammonoides (Reuss).

Rosalina ammonoides, Reuss, 'Verstein. böhm. Kreid.' pt. i. (1845) p. 36, pl. viii. fig. 53, pl. xiii. fig. 66.

Anomalina ammonoides, Brady, 'Challenger' Rep. vol. ix. (1884) p. 672, pl. xciv. figs. 2, 3.

This species is a well-known Cretaceous and Tertiary fossil, and is also found in recent deposits, from depths of 37 to 1350 fathoms.

Two specimens were found in the Pebble-beds, Littleton.

132. Anomalina grosserugosa (Gümbel).

Truncatulina grosserugosa, Gümbel, Abhandl. bayer. Akad. Wissensch. 2te Cl. vol. x. (1868) p. 660, pl. ii. fig. 104 *a*, *b*.

Anomalina grosserugosa, Brady, 'Challenger' Rep. vol. ix. (1884) p. 673, pl. xciv. figs. 4, 5.

This is a fairly deep-water species, and it also occurs fossil in beds of Tertiary age.

One specimen from the Pebble-beds, Littleton.

Pulvinulina, Parker & Jones.

133. Pulvinulina punctulata (d'Orbigny).

Rotalina punctulata, d'Orbigny, Ann. Sci. Nat. vol. vii. (1826) p. 273, no. 25: Modèle no. 12.

Pulvinulina punctulata, Brady, 'Challenger' Rep. vol. ix. (1884) p. 685, pl. civ. fig. 17 *a–c*.

A small and not very typical example of this species was found in the Pebble-beds, Littleton.

134. Pulvinulina Schreibersii (d'Orbigny).

Rotalina Schreibersii, d'Orbigny, 'Foram. Foss. Vienne,' 1846, p. 154, pl. viii. figs. 4–6.

Pulvinulina Schreibersii, Brady, 'Challenger' Rep. vol. ix. (1884) p. 697, pl. cxv. fig. 1 *a–c*.

This species appears to be restricted to shallow water. As a fossil it had hitherto made its first appearance in Miocene strata.

One specimen from the Pebble-beds, Littleton.

135. Pulvinulina Karsteni (Reuss).

Rotalia Karsteni, Reuss, Zeitschr. deutsch. geol. Gesellsch. vol. vii. (1855) p. 273, pl. ix. fig. 6.

Pulvinulina Karsteni, Brady, 'Challenger' Rep. vol. ix. (1884) p. 698, pl. cv. figs. 8, 9.

P. Karsteni has been recorded from beds of Upper Cretaceous age, and also from later Tertiary formations. As a recent form it appears to be restricted to shallow water, and it is usually found in high latitudes.

Four specimens from the Pebble-beds, Littleton.

136. Pulvinulina elegans (d'Orbigny).

Rotalina (Turbinulina) elegans, d'Orbigny, Ann. Sci. Nat. vol. vii. (1826) p. 276, no. 54.

Pulvinulina elegans, Brady, 'Challenger' Rep. vol. ix. (1884) p. 699, pl. cv. figs. 4–6.

P. elegans seems to make its earliest appearance in beds of Liassic age, and it is found in most important formations of later date. The species is closely allied to *P. Partschiana* (d'Orbigny), but the former represents the shallow-water type, and it is this form which is present in the Bargate series of foraminifera.

One specimen from the Pebble-beds, Littleton.

ROTALIA, Lamarck.

137. ROTALIA BECCARII (Linné).

Nautilus Beccarii, Linné, 'Syst. Nat.' 12th ed. (1767) p. 1162; ibid. 13th (Gmelin's) ed. (1788) p. 3370, no. 4.

Rotalia Beccarii, Brady, 'Challenger' Rep. vol. ix. (1884) p. 704, pl. cvii. figs. 2, 3.

This species has been noted from Upper Cretaceous strata, as well as from beds of later age, and is well known as a shallow-water form.

One specimen from the Pebble-beds, Littleton.

Family NUMMULINIDÆ.

Subfamily POLYSTOMELLINÆ.

NONIONINA, d'Orbigny.

138. NONIONINA SCAPHA (Fichtel & Moll).

Nautilus scapha, F. & M. 'Test. Micr.' 1803, p. 105, pl. xix. figs. *d–f*.

Nonionina scapha, Brady, 'Challenger' Rep. vol. ix. (1884) p. 730, pl. cix. figs. 14, 15, and 16?

This species has been noted from beds of Miocene age, and others of later date.

One specimen was found in the Bargate Pebble-beds at Littleton, which is not very typical, but somewhat closely resembles fig. 16 in the 'Challenger' Rep. (*loc. cit.*).

POLYSTOMELLA, Lamarck.

139. POLYSTOMELLA ACULEATA, d'Orbigny.

P. aculeata, d'Orbigny, 'Foram. Foss. Vienne,' 1846, p. 131, pl. vi. figs. 27, 28.

This species was originally described from the Miocene; and it occurs in the Bargate Pebble-beds at Littleton (two specimens).

In the foregoing notes upon the foraminifera of the Bargate Beds of Surrey, 139 species and varieties are recorded.

Of these, 11 are described for the first time. There are, besides, 107 which have hitherto been unrecorded (so far as I am aware) from beds of Neocomian age.

The following 10 species and varieties have been known previously from recent deposits only, namely, *Haplophragmium foliaceum*, Brady; *Virgulina subdepressa*, Brady; *Ehrenbergina pupa* (d'Orbigny); *Polymorphina sororia*, Reuss, var. *cuspidata*, Brady; *P. oblonga*, Williamson; *P. regina*, Brady, Parker, & Jones; *Discorbina Bertheloti* (d'Orbigny); *D. concinna*, Brady; *D. Vilardeboana* (d'Orbigny); and *D. araucana* (d'Orbigny).

The large number of forms new to the Neocomian fauna, as known elsewhere, is undoubtedly due to the circumstance that the deposits of the Bargate series belong almost exclusively to the Laminarian and Coralline zones.

Taking into consideration the facts that 23 per cent. of the forms here recorded are almost peculiarly Neocomian types, that these added to known Cretaceous and Tertiary species amount to 122 or 87 per cent. (the latter additions probably being due to the fact that the Neocomian strata have not been so extensively examined in regard to their Rhizopodal fauna as might have been desired), it is extremely probable that the microzoic fauna of the Bargate series is almost entirely, though (since we have the presence of a few Jurassic species) not quite indigenous to the deposit.

In conclusion, I tender my sincerest thanks to Prof. T. Rupert Jones, F.R.S., and Prof. J. W. Judd, F.R.S., for much invaluable aid and advice; to Dr. G. J. Hinde, for his kindness in furnishing the notes upon the sponge-spicules; to Dr. W. Fraser Hume, F.G.S., for the valuable notes on the denser minerals of the sands f the Bargate series; to Graf zu Solms-Laubach of Strasburg, a d G. Murray, Esq., of the Botanical Department of the British Museum of Natural History, for examining the alga-like bodies of the Bargate limestone; and to Dr. J. W. Gregory for his kind assistance regarding some of the doubtful polyzoan remains.

DISTRIBUTION OF THE OSTRACODA IN THE BARGATE BEDS OF SURREY.

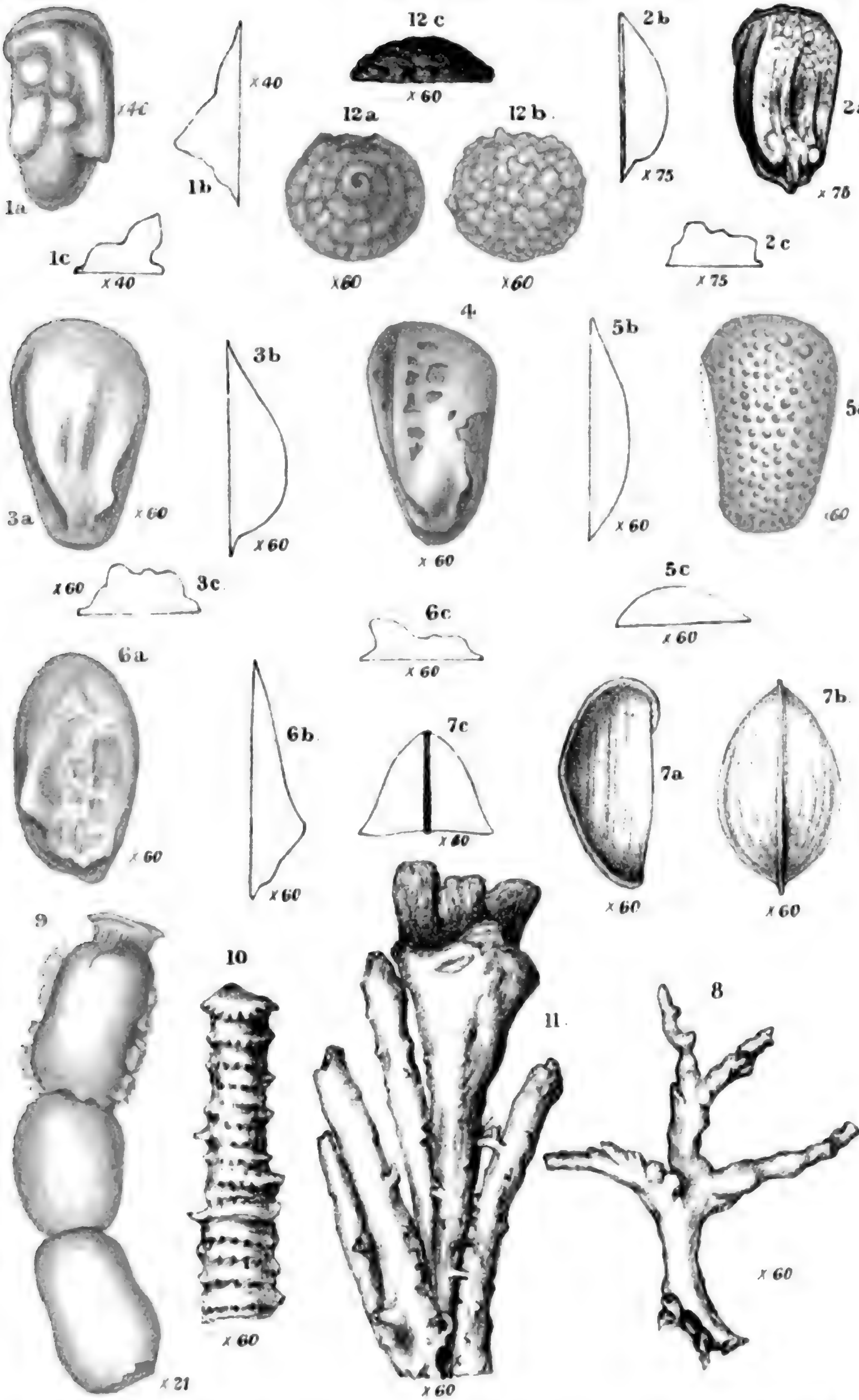
		Littleton.	Chilworth.
1.	Cythere vesiculosa, *sp. nov.*	*	
2.	Cythereis ornatissima (*Reuss*)	*	
3.	,, ,, *var.* reticulata, *J. & H.*	*	
4.	,, Lonsdaleana, *Jones*	*	
5.	Cytheridea retorrida, *J. & S.*	*	
6.	,, subperforata, *Jones*	*	*
7.	,, rotundata, *C. & S.*	*	
8.	,, bicarinata, *J. & S.*	*	
9.	,, ,, *var.* nodulosa, *var. nov.*	*	
10.	,, vellicata, *sp. nov.*	*	
11.	,, fenestrata, *sp. nov.*	*	
12.	,, craticula, *J. & S.*	*	
13.	,, bipapillata, *sp. nov.*	*	
14.	Cytheropteron concentricum (*Reuss*)	*	*
15.	,, ,, *var.* virginea, *Jones*	*	
16.	,, subconcentricum (*Jones*)	*	
17.	,, drupaceum (*Jones*)	*	
18.	,, laticristatum (*Bosquet*)	*	
19.	,, reticulosum, *sp. nov.*	*	
20.	,, costuliferum, *sp. nov.*	*	

DISTRIBUTION OF THE FORAMINIFERA IN THE BARGATE BEDS OF SURREY.

		Littleton.	Chilworth.	Godalming.	Dorking.
1.	Miliolina agglutinans (*d'Orb.*)	...	...	*	
2.	Planispirina obscura, *sp. nov.*	*			
3.	Haplophragmium agglutinans (*d'Orb.*)	...	...	*	
4.	„ Humboldti (*Reuss*)	*			
5.	„ irregulare (*Röm.*)	*			
6.	„ foliaceum, *Brady*	...	...	*	
7.	„ emaciatum, *Brady*	*			
8.	„ acutidorsatum, *Hantken*	*			
9.	„ neocomianum, *sp. nov.*	*	*	*	
10.	„ nonioninoides, *Reuss*	*	*	*	
11.	„ depressum, *Jones*	*	...	*	*
12.	Ammodiscus incertus (*d'Orb.*)	*	...	*	*
13.	„ gordialis (*J. & P.*)	*	...	*	*
14.	„ charoides (*J. & P.*)	*			
15.	„ pleurotomarioides, *sp. nov.*	*			
16.	Trochammina squamata, *J. & P.*, *var.* limbata, *var. nov.*	*	...	*	*
17.	Textularia sagittula, *Defr.*	...	...	...	*
18.	„ gramen, *d'Orb.*	*	...	*	*
19.	„ prælonga, *Reuss*	*	...	...	*
20.	„ minuta, *Berthelin*	*			
21.	„ agglutinans, *d'Orb.*	*			
22.	„ trochus, *d'Orb.*	*			
23.	„ turris, *d'Orb.*	*			
24.	Verneuilina triquetra (*Munst.*)	*			
25.	Tritaxia tricarinata, *Reuss*	*	*		
26.	Spiroplecta annectens (*P. & J.*)	*	...	*	
27.	„ biformis (*P. & J.*)	*	...	*	*
28.	Gaudryina pupoides, *d'Orb.*	*	...	*	
29.	„ baccata, *Schwager*	...	...	*	
30.	„ filiformis, *Berthelin*	*			
31.	Valvulina conica, *P. & J.*	...	...	*	
32.	„ fusca (*Will.*)	*			
33.	Bulimina polystropha, *Reuss*	*	...	*	*
34.	„ pupoides, *d'Orb.*	*	...	...	*
35.	„ affinis, *d'Orb.*	*	...	*	
36.	„ ovata, *d'Orb.*	*	...	*	
37.	„ pyrula, *d'Orb.*	*			
38.	„ obliqua, *d'Orb.*	*	*	*	
39.	„ Presli, *Reuss*	*			
40.	„ obtusa, *d'Orb.*	*	*	*	
41.	„ Murchisoniana, *d'Orb.*	*			
42.	„ brevis, *d'Orb.*	*	*	*	*
43.	Virgulina subsquamosa, *Egger*	*	...	*	
44.	„ subdepressa, *Brady*	*			
45.	Bolivina textilarioides, *Reuss*	*			
46.	(?) „ dilatata, *Reuss*	*			
47.	Cassidulina subglobosa, *Brady*	*			

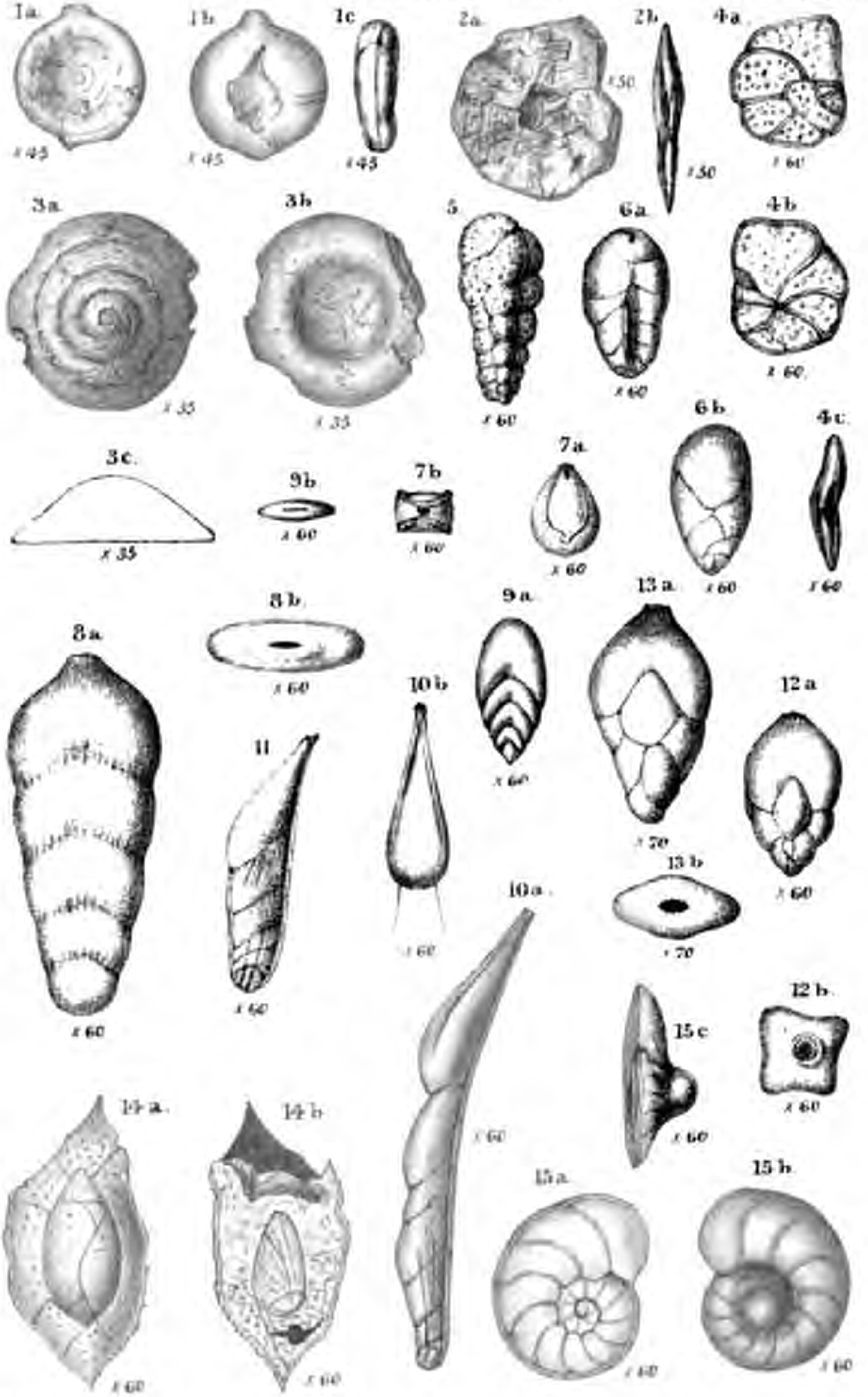
DISTRIBUTION OF THE FORAMINIFERA (*continued*).

		Littleton.	Chilworth.	Godalming.	Dorking.
48.	Ehrenbergina pupa (*d'Orb.*)	*			
49.	Lagena globosa (*Mont.*)	*	*		
50.	,, apiculata, *Reuss*	*			
51.	,, lævis (*Mont.*)	*			
52.	,, acuticosta, *Reuss*	*			
53.	,, Meyeriana, *sp. nov.*	*			
54.	Nodosaria (Dentalina) brevis, *d'Orb.*	*			
55.	,, (,,) Roemeri, *Neug.*	*			
56.	,, (,,) xiphioides, *Reuss*	*			
57.	,, limbata, *d'Orb.*	*			
58.	,, Fontannesi, *Berth.*	*			
59.	,, (D.) obscura, *Reuss*	*			
60.	,, tenuicosta, *Reuss*	*			
61.	,, prismatica, *Reuss*	...	*		
62.	Lingulina carinata, *d'Orb.*	*			
63.	,, semiornata, *Reuss*	*			
64.	,, ,, *var.* crassa, *var. nov.*	*			
65.	Frondicularia brizæformis, *Born.*	*			
66.	Marginulina linearis, *Reuss*	*			
67.	,, debilis, *Berthelin*	*			
68.	,, compressa, *d'Orb.*	*			
69.	,, æquivoca, *Reuss*	*			
70.	,, Jonesi, *Reuss*	*	*		
71.	,, striatocostata, *Reuss*	*			
72.	,, Munieri, *Berthelin*	*			
73.	Vaginulina legumen (*Linné*)	*			
74.	,, arguta, *Reuss*	*			
75.	,, sparsicostata, *Reuss*	*			
76.	,, neocomiana, *sp. nov.*	*			
77.	Cristellaria tricarinella, *Reuss*	*	*		
78.	,, vestita, *Berthelin*	*			
79.	,, italica (*Defr.*)	*			
80.	,, sulcifera, *Reuss*	*			
81.	,, complanata, *Reuss*	*			
82.	,, parallela, *Reuss*	*			
83.	,, Schloenbachi, *Reuss*	*	*		
84.	,, crepidula (*F. & M.*)	*			
85.	,, grata, *Reuss*	*			
86.	,, cymboides, *d'Orb.*	*			
87.	,, lævigata, *Reuss*	*			
88.	,, acutauricularis (*F. & M.*)	*			
89.	,, Bronni (*Röm.*)	*	*		
90.	,, oligostegia, *Reuss*	...	*		
91.	,, rotulata (*Lam.*)	*	*		
92.	,, cultrata (*Montf.*)	*	*		
93.	,, gibba, *d'Orb.*	*	*		
94.	,, convergens, *Born.*	*			
95.	,, prominula, *Reuss*	*			
96.	,, megalopolitana (*Reuss*)	*			
97.	,, varians, *Born.*	*			



F. Chapman del. F. H. Michael lith. Mintern Bros. imp.

BARGATE MICROZOA.



F. Chapman del. F. H. Michael lith. Mintern Bros. imp.

BARGATE FORAMINIFERA

[illegible]

was just such as in a smaller or less clearly exposed section would be ascribed to an unconformity, but it was clearly false-bedding. He thought that the Society was much indebted to the Author of the paper for his microscopical work, which he hoped would be continued, because it would be an advantage if certain beds of the Lower Greensand could be correlated thereby; for instance, if the beds of the Horsham Road-cutting could be correlated by means of the foraminifera, a great result would be obtained by the examination of these small organisms.

Prof. JUDD called attention to the great importance of the Author's researches, not only in increasing our knowledge of the Cretaceous microzoa, but in giving evidence of the existence in the immediate neighbourhood of the district described by him of Jurassic rocks, for he has found a Lower Greensand rock filled with derived grains of oolite, like those occurring in the Richmond boring.

Mr. WHITAKER, Dr. G. J. HINDE, Mr. TOPLEY, and Prof. T. RUPERT JONES also spoke.

[NOTE.—In the abstract of this paper—which was submitted to the Secretary by the Author—an unconformity was inadvertently mentioned as occurring between the Folkestone and the Bargate Beds. As in the paper itself, it should have been referred to as an eroded surface (contemporaneous erosion).—Sept. 7th, 1894.]

43. CONE-IN-CONE: *How it* OCCURS *in the* 'DEVONIAN' SERIES *in* PENNSYLVANIA, U.S.A., *with further* DETAILS *of its* STRUCTURE, VARIETIES, *etc.* By W. S. GRESLEY, Esq., F.G.S. (Read May 9th, 1894.)

[Abridged.]

[PLATES XXXV. & XXXVI.]

THE objects of this communication are:—(1) to clearly demonstrate that cone-in-cone, in its normal condition, very frequently possesses 'inverted cones,' *i. e.* cones with their apices pointing upwards, as ΛΛ, as distinguished from what may be called 'ordinary' cone-in-cone, wherein the points of the cones face downwards, as VV; (2) to show that Mr. John Young's explanation of the formation of both the ordinary and the inverted cones is probably erroneous,[1] because it altogether fails to account for the phenomena observed; and (3) to describe certain forms and inner structures of the rock, not hitherto published; concluding with a few suggestions regarding the probable origin and mode of formation of the conic masses.

1. Inverted Cones.

Instances of layers of cone-in-cone forming portions of nodules were referred to in 1820,[2] but, so far as I know, no trustworthy illustrations of inverted cones appeared until those given in my own paper in 1887.[3] Now, these 'finds' seem to afford sufficient evidence to prove that Mr. Young's theory of cone-formation must be rejected, provided (as it is natural and reasonable to suppose) that true cone-in-cone can be produced in one way alone. But Mr. Young, having come to the conclusion that the Scottish cone-in-cone, from which he obtained his specimens and constructed his theory, was a formation resulting from the ebullition of gases passing upwards through a plastic sediment during deposition in local areas, altogether repudiated the idea of true conic layers having the bases of the cones facing downwards. He endeavoured to account for the existence of nodules upon whose upper surfaces cone-in-cone occurred with the points in the direction of centre of the mass, and upon whose under surfaces similar structures existed with their apices facing in the same direction, by employing the phenomenon of contraction. This he conceived had acted so powerfully on these cone-in-cone-concretions as to cause them to curl up, hedgehog-like, to such an extent that the conic layer on the top was stretched and even carried round to, and presumably welded together upon, the under side. The very aspect and structure of the nodules that I had studied prevented me from accepting, even for a moment,

[1] Trans. Geol. Soc. Glasgow, vol. viii. (1885) p. 1.
[2] Trans. Geol. Soc. ser. 1, vol. v. pt. 2, p. 375.
[3] 'Notes on Cone-in-cone Structure,' Geol. Mag. p. 17.

that explanation; and as my illustrations of inverted cone-in-cone were, in effect, slighted by Mr. Young, the next thing to be done, in order to positively demonstrate the existence of inverted cones, was, if possible, to discover such specimens of the formation as could be photographed *in situ*. There could then be no possibility of error of observation, nor any room left for doubt that the conic masses were not bent or curled round so as to bring the originally flat cone-in-cone upside down upon the under side of the containing rock or nodule. Mr. Young wrote[1]:—"Since my paper was printed in 1886, I have obtained many other illustrative specimens from our Scottish coalfield. These clearly show that the radiation and inversion of the cones, in nodular masses, was due to after-secondary causes, the cone structure being first, the formation of the nodules being second, and the amount of radiation, and inversion of the cones, affords a measure of evidence as to the amount of contraction that has taken place amongst these nodules previous to complete solidification." Why Mr. Young did not supply a good illustration of a typical sample of one of these curiously-inverted cone-in-cone-bearing nodules we were not informed; perhaps he will favour us with one after he has seen this paper, so that they may be compared with the specimens herein described.

2. Typical Inverted or Double Cone-in-cone, in the Portage Flags, Pennsylvania.

In 1890 the present writer came to reside at Erie, Pa., and it rather curiously happened that this very locality, which is situated on Lower Carboniferous or Devonian (?) strata, was a noted one for cone-in-cone.[2] Moreover, I was furnished with a copy of a paper on the Erie cone-in-cone, written in 1880, by Dr. T. D. Ingersoll of that city, whose valuable aid in discovering specimens and working up the subject I have pleasure in acknowledging here. The cone-structure is very prevalent in North-western Pennsylvania; it occurs on the horizon of a very persistent bed of limestone, called the Ferriferous Limestone. This is a stratum usually several feet thick; but almost always, when and wherever it thins down to about 4 inches or less, the cone-in-cone formation has been developed in it and the limestone is quite earthy. But it is several hundred feet deeper in the series that the formations which constitute the subject of this paper are met with.

The typical cone-in-cone in the vicinity of Erie occurs at several more or less definite horizons in the Portage series. These rocks lie almost horizontally, cropping out boldly in cliffs of moderate elevation all along the southern shore of Lake Erie for 80 or 90 miles, and as the coast is cut into every few miles by streams entering the lake through ravines, excellent opportunities are afforded of

[1] Geol. Mag. 1892, p. 279.
[2] Pennsylv. 2nd Geol. Surv. Report, Q 4 (1881), p. 291.

tracing and scrutinizing the various layers of shale, sandstone, etc., and of gaining access to the innumerable and varied exposures of cone-in-cone which they enclose. The Portage strata here are marvellously uniform in character and composition: thin, flaggy, current-bedded, pale-grey sandstones are interbedded with laminated shales of various shades of purple, grey, etc., the changes from one layer to another being very frequent; but horizontally, each bed, band, or layer maintains its individuality in a marked degree. The shales, as well as the surfaces of the more siliceous beds, reveal abundant evidence of organic life—we find trails, tracks, and burrows of worms and other creeping things by the myriad; fucoids, etc. are not uncommon; mud-flows, rill and ripple-markings innumerable, besides very numerous other markings of a puzzling nature.[1] While a few of the sandstone-layers become thick enough here and there to quarry, the shales, though often containing alum and lime, are never worked. Natural gas and a little petroleum pervade the strata to some extent.

The cone-in-cone seems to occur on certain definite horizons and to lie parallel with or interbedded in the shales, etc. It occurs in separate patches, discs, aggregated or clustered layers or flattish cakes, whose contour is round or irregular-curvilinear. Within a horizontal distance of 100 feet one may come upon half a dozen or more individual conic masses on the same plane, while in the next 100 or even 1000 feet none may be found. In general dimensions 20 feet across or long is the size of the largest single layer that the author has seen; and individual masses more than 6 or 6½ inches in thickness are very scarce. In the separate layers or lenses the heights of the cones never exceed about 4 inches and often run as low as $\frac{1}{20}$ inch: indeed, they taper or die out to nothing. Some conic masses are composed of as many as six or eight separate heights or zones of cone-in-cone layers one above another, no two layers being of uniform dimensions, and the apices of the cones of the lower layers are directed upwards, or rather towards the central stratum of the mass. Very few of the layers of cone-in-cone occur singly.

The cone-structure is harder than the surrounding strata, but in coloration there is practically no difference. Both upper and lower surfaces of the layers of cone-in-cone often present a wavy form, such as is seen in most current-bedded fissile sandstones. Pl. XXXV. fig. 1 shows a naturally exposed and weatherworn transverse section of a characteristic aggregate of individual and separated layers of the cone-in-cone *in situ*, forming or constituting a typical Portage conic mass: in this specimen there are three separate layers of cones above the nucleus or central layer. This nucleal layer lies just above the dark shadow to the right of the watch. In Pl. XXXV. fig. 2 this specimen is drawn in diagrammatic form, in order to bring out more clearly the relative position and number of conic cakes revealed in the mass: it also gives point to the nucleal stratum—a current-bedded stone, and the leading features of the

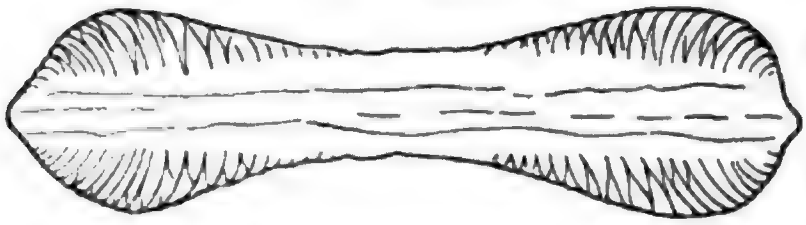
[1] Pennsylv. Geol. Surv., Summary Final Report, vol. ii. (1892) p. 1349.

surrounding shales. Upon the layer of stone are two separated cakes of cones on the same plane—one above the watch, the other over the dark cavity below the core or nucleus. Above and between these two cone-patches is a layer of shale. Over this comes a well-developed layer of cones, then another shale-layer, and above that the third height of cones, which thins out before it reaches the edges of the underlying conic layer. Just beneath the core or nucleus, and level with the bottom of the watch, the *inverted* conic layer occurs, as the figure more or less clearly shows.

No two conic masses appear to be alike; not only do the size, position, thickness, perfection, and number of the overlying and the underlying (ordinary and inverted) conic cakes vary extremely, but the entire structure—the *tout ensemble* of the formations—is very curious, differentiation being a decided feature.

We find then that this cone-in-cone is characterized by its sandwiched, or cake-above-cake, shale—or sandstone—interbedded structure, and possesses an obvious and yet an indefinite nucleus-like centre, towards which the cones and parts of cones radiate. But the nucleus of these Portage masses is not usually a nodule[1]; it is only

Section through a typical cone-in-cone-bearing nodule, Portage Series, Pennsylvania.



[The cone-in-cone portions are confined to broad circular bands, tapering away at their edges, upon both the upper and lower surfaces.]

a portion of what appears to be an ordinary layer of false-bedded sandstone. Now, where the sandstone comes within the range or confines of the conic masses it is decidedly calcareous. The cone-in-cone invariably contains calcium carbonate, while the enveloping layers of shale rarely show more than a trace of that salt.

It is important also to notice that cone-in-cone, although associated and sometimes intricately intercalated with the thin arenaceous laminæ, is nevertheless confined to the more argillaceous—the shaly layers. Another feature is that an individual layer or lenticular cake of the structure has not restricted itself in process of formation to any one particular band of the shale, but, as shown in Pl. XXXV. fig. 5, incorporates portions of several different bands.[2] That there exists any difference in any particular between the conic

[1] When well-developed nodular masses carrying cone-in-cone do occur in these beds, the upper and lower coatings of the cones, instead of being drawn around the rims of the nodules (as Mr. Young appears to find them), are squeezed and somewhat elevated into annular forms near the rims of the stone on either side (see fig.).

[2] Does not this fact alone prove that Mr. Young's idea of the origin, etc. of the formation cannot stand?

structures, normal and inverted, I have failed to perceive; unless one knows which is which, by actually seeing it and marking it *in situ*, it is not possible to tell whether a specimen is of inverted cones or not. This remark applies to entire assemblages of conic cakes (*e. g.* Pl. XXXV. fig. 1), as well as to separate layers of cones (Pl. XXXV. fig. 5). Dr. Ingersoll possesses specimens of cone-in-cone from the Pacific coast, California. These the author has examined, and he sees no material difference between them and the Pennsylvanian Portage cones; in fact, they are remarkably similar.

3. Detailed Description of the Cone Formation.

The largest, best developed, and most perfect individual cones of any separate conic cake are usually found near the centre of the cake. They are surrounded laterally by numerous, more or less scaly or flaky segments of cones, generally arranged concentrically with the larger cones, and wrap round or dovetail into each other, being more and more obliquely inclined towards the bedding-planes as they approach the rim of the disc (see Pl. XXXV. figs. 2 & 5), where they dwindle down to nothing. Viewed in the direction of the axes of the cones, their apices have a minutely oolitic aspect; that is, the points of all the cones or parts thereof which occupy or start from the apex-plane of the conic cakes resemble the spotted surface of oolite, though in reality every apex is probably as fine as a pin-point (Pl. XXXVI. fig. 20). A characteristic feature of the cone-structures is that the bases of the cones and 'conic scales' (Pl. XXXV. fig. 3) in transverse section reveal a serrated surface (Pl. XXXV. fig. 5); the outer edges of separate conic scales project a little beyond, as well as over the inner and lower margin of the adjacent scales. But instead of asking the reader to follow closely several pages descriptive of each important detail in the structure of cone-in-cone (most of which details have been described elsewhere by Sorby, Newberry, Dawson, Young, Cole, Dickinson, Marsh, Mantell, and the author, and are probably more or less well-known or easily accessible to Fellows of this Society), the writer would ask them to carefully study the illustrations which accompany this paper and the explanations annexed to them. With regard to the 'clayey' or 'dark rings' of Mr. Young, and the microscopical structure of the formation (as the material of the walls of the cones and conic scales may, for convenience, be termed), I would draw the reader's particular attention to Pl. XXXV. figs. 7, 8, 10 and 10 *a*, and Pl. XXXVI. figs. 11, 12, 13 and 13 *a*, and 14.

Previously to the present writer's first paper on cone-in-cone,[1] no one appears to have studied or published anything relating to the microscopical structure. Mr. Young's specimens do not seem to have revealed anything of it, beyond the clayey rings on the backs of the cones. Prof. G. A. J. Cole, however,[2] observed it and confirms my

[1] Geol. Mag. 1887, p. 17.
[2] Mineralog. Mag. vol. x. (1893) p. 136.

notice of it, but the illustrations which accompany his paper do not seem to be of specimens sufficiently well-developed to display the structures referred to, namely, those brought out in Pl. XXXVI. figs. 11 and 12. I also venture to believe that my illustrations (Pl. XXXV. figs. 7 and 8), which show the curiously wrinkled or corrugated surfaces of the bases of the cone-in-cone, are new in this connexion.

Assuming, then, that the all-important characteristics and sufficient detail of the cone-material have been grasped and fairly understood—for so complex a structure is by no means easy to describe, however easy it may be to illustrate,—we may now proceed to summarize the observed facts and draw deductions therefrom.

4. Conclusions.

(1) The perfectly normal and practically unchanged and undisturbed condition of the cone-in-cone-bearing Portage Beds in North-western Pennsylvania furnish conclusive evidence that this cone-in-cone is there in place, and moreover that it was formed since and not *pari passu* with the enclosing strata. It is therefore a secondary product, and a product of *alteration*.

(2) The nests or multiple-heights (one layer above another) of the conic material, from their very position or lie in the strata, show that they were formed simultaneously; but how long the process took, at what depth it operated, and whether it is going on still or not, we do not know.

(3) That each and every individual layer, as well as nest of cones, has been formed from practically the same materials and in the same manner is sufficiently obvious.

(4) The cone-forming conditions (whatever they were) evidently had an affinity for certain horizons in the Portage series, and were also such that the cone-formations were originated more in one place than another—they seem to be numerous in some places, scarce or absent in others, on the same stratigraphical horizon.

(5) The cone-in-cone avoids the harder and more sandy layers, but does not occupy the whole thickness of the shaly layers interbedded, in very frequent alternations, with the sandy ones. The core or nucleal layer of the conic masses certainly contained the 'germ,' so to say, of the structures (probably some fossil); and, as it contains a considerable quantity of calcium carbonate, which outside of the conic layers is absent, and which also pervades other arenaceous laminæ that have been incorporated in the 'unconed' parts of the structure, it is evident that lime was an essential agent in the phenomena.

(6) The swelling which occasionally accompanies cone-in-cone is probably due to the acquisition of lime from without by the cones as they were forming,—a process which resulted in a thrusting-aside vertically of the enveloping layers, in a manner often observable in connexion with Coal-Measure nodules, and with nodules of marcasite and pyrites in coal.

(7) The phenomena of the corrugated and wrinkled surfaces, both upon the sides and the bases of the cones, the dark clayey lateral ridges or rings encircling the cones, and the serrations upon the bases of the cone-layers, all appear to indicate unmistakably the operation of lateral radial contraction, squeeze, or pressure acting towards the centre of the formations.

(8) Further, an inspection of the minute texture of the walls of the cones reveals a semi-crystalline structure,—namely, innumerable aggregates of miniature or semi-microscopic cone-in-cone comparable with the main structure.

(9) Thus the conclusion is reached that cone-in-cone must be regarded as a species of concretion, whose peculiar mineral and chemical composition induced such pressure among the particles while undergoing transformation as to produce the forms of cones and (by differentiation) parts of cones all through the separate layers, collectively and yet independently.

In other words, this cone-in-cone is a final product of the concentration of calcium carbonate around certain nucleal points within, or horizontal planes of original stratification of, detrital sedimentary fossiliferous rocks; which accretionary process involved the partial expulsion of the non-crystallizing contained clayey material, and this material, seeking or struggling, in obedience to the laws of crystallization, to escape, was perforce (owing to close confinement all around, with ever-increasing contractile inward and radial pressure tending to keep it back) compelled to assume the form of horizontal rings or ridges: and these were the weakest places which the pressure-produced conic cleavage afforded. The calcareous semi-crystalline fabric of cones having completed its mutations or gone through the requisite evolutions, with the argillaceous rings of squeeze brought into equilibrium with the rest of the structure, cone-in-cone was complete.

Finally, the observed structures in the typical Portage cone-in-cone agreeing, as they do, closely in every essential particular with the cone-in-cone of the Coal Measures in Great Britain and in North America, impel the present writer to regard the origin and formation of one and all as practically identical in original composition—chemically and physically,[1] and, in the main, to accept the conclusions of other observers in this connexion, who consider the formation to be a result of pressure acting upon concretions.

[1] Many examples of cone-in-cone, as they exist to-day, are unquestionably what may be called *re*-altered products—that is, 'tertiary' formations; for the author's collection contains cone-in-cone composed of hæmatite, limonite, ferriferous quartzite, quartzite, pyrites or marcasite, and a variety of more or less iron-impregnated siliceous rocks.

EXPLANATION OF PLATES XXXV. & XXXVI.

[All the specimens, unless otherwise stated, are from the Portage Flags (Devonian?) of Erie, Pennsylvania.]

PLATE XXXV.

Fig. 1. Photograph of an exposure of a typical mass of 'cone-in-cone' *in situ* in the cliffs of the southern shore of Lake Erie, 2 miles N.E. of the city of Erie, exhibiting a transverse section of the formation occurring near the middle of the Portage Flags.

Fig. 2. Diagrammatic view of the conic mass in fig. 1, showing the chief characteristic features (stratigraphical and structural) of the several layers of cone-in-cone in relation to the central sandstone or nucleal band, above and below which the cones point in opposite directions.

Fig. 3. A perfect or typical cone 'a,' encircling which are several portions of cone-in-cone structure or conic scales, 'b,' 'c,' 'd,' which shows the relative position of the parts or structure of the formation, as revealed in any one or all of the different layers of cones pervading the conic masses in fig. 2.

Fig. 4. Portion of a conic cake in contact with, and having tongues or offshoots of, the cone-formation running into the nucleal stratum.

Fig. 5. Portion of a cake or layer of inverted cone-in-cone, through which passes a thin stratum of dark argillaceous shale between two lighter-coloured layers of similar material, the dark band being thicker where it has become 'cone-in-conized.'

Fig. 6. Portion of an inverted layer of cones, next to a thin bed of calcareous sandstone: this specimen, on weathering, has split along the bedding-plane separating the cones from the sandy layer.

Fig. 7. A small portion of the bases of cones and conic scales of a typical layer of the formation, exhibiting the characteristic corrugated or differentially wrinkled surfaces, as well as the curvilinear lines which are the divisional planes of the cones. There is also seen a small conical depression, and two or three little conical peaks.

Fig. 8. Transverse section of cone-material between well-developed cones (not shown), illustrating the wrinkles of the bases of the cones, and the continuation of the wrinkling down the surfaces of the conical hollows in which the cones occur.

Fig. 9. Perspective view of part of a conic cup (cone removed), showing the differentially wrinkled surface referred to in fig. 8, increasing in size and strength towards the rim.

Figs. 10 & 10*a*. View of a good cone (fig. 10), showing how its surface is ringed horizontally with irregular flounce-like appendages of fibrous calcareous material, which die away to mere streaks as the apex of the cone is approached. Fig. 10*a* shows two of these rings in cross section, magnified about 5 times.

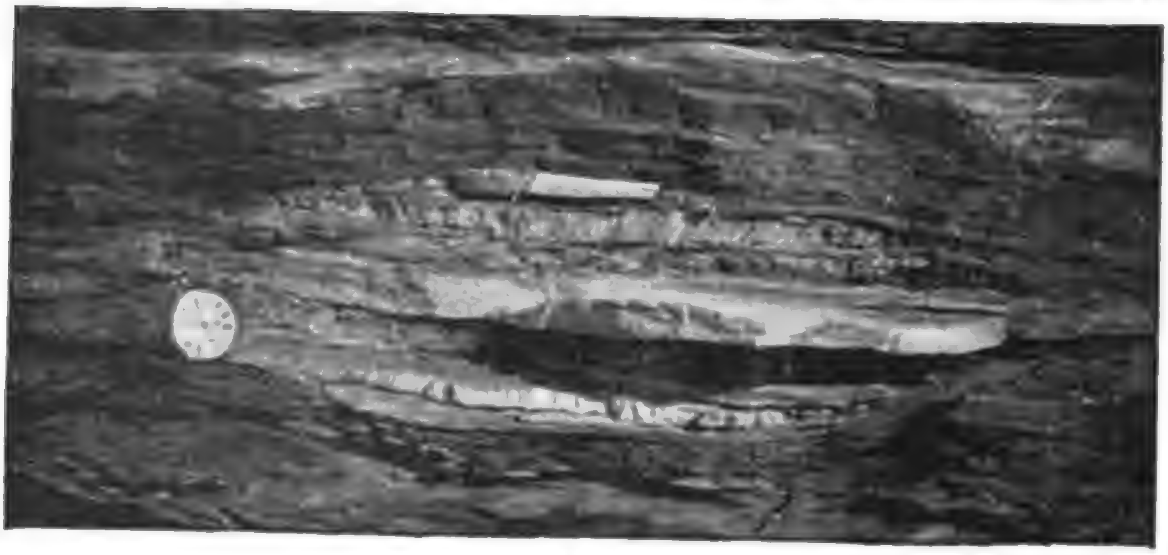
Fig. 24. One of the numerous dark specks (? an organism) promiscuously scattered through the cone-in-cone layers, and seen outside them also (see figs. 7, 15, & 21), magnified 10 times.

PLATE XXXVI.

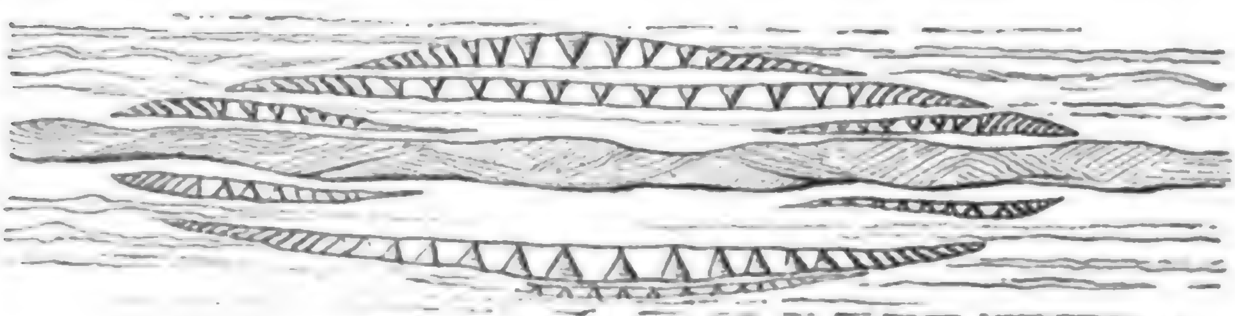
Fig. 11. Diagrammatic view through a complete cone, exhibiting the connexion between, or the relative positions of, the corrugated surfaces shown in figs. 7, 8, 9, & 10, and the intervening clayey material (black) encircling the cone.

Fig. 12. Enlarged view of a portion of the right side of the conic scales enclosing the cone of fig. 11, showing the feathery or splay-shaped arrangement of cone-in-cone structures lapping around one another, and separated by the calcareous and the non-calcareous rings (see Pl. XXXV. fig. 10*a*, and the black portions of Pl. XXXVI. fig. 11), magnified 4 times.

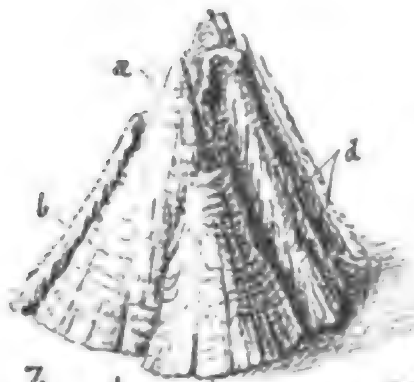
Figs. 13 & 13*a*. Diagrammatic view and plan of base, respectively, of a strong cone, encompassed by typical structure (shown in figs. 7–12 inclusive),



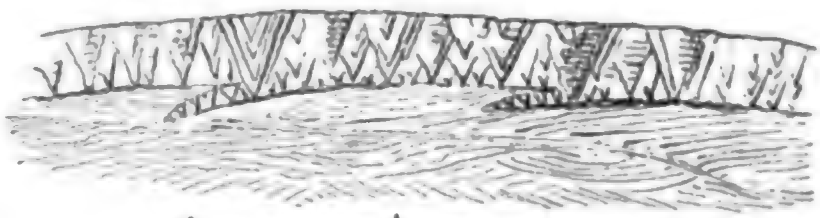
1 $\frac{1}{8}$



2. $\frac{1}{8}$



3 $\frac{1}{1}$



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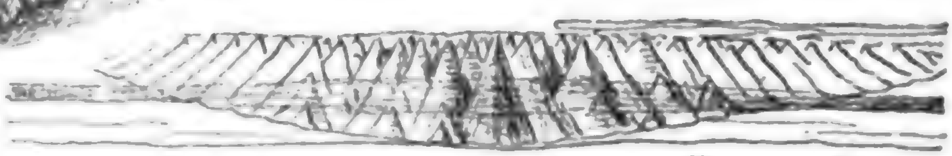

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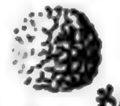
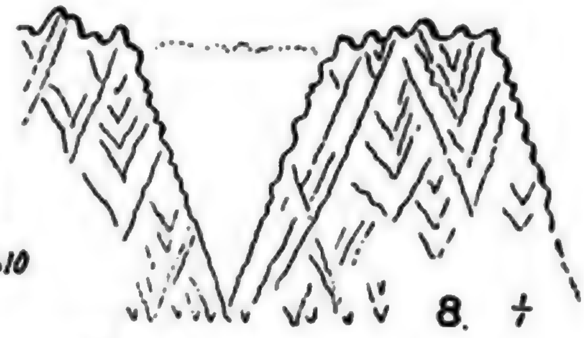
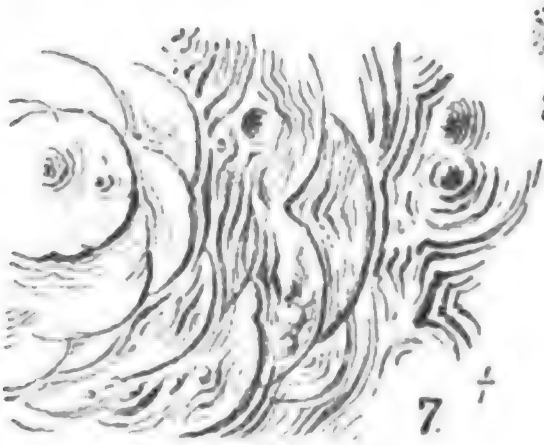


24 ×10



8. $\frac{1}{1}$



7 $\frac{1}{1}$

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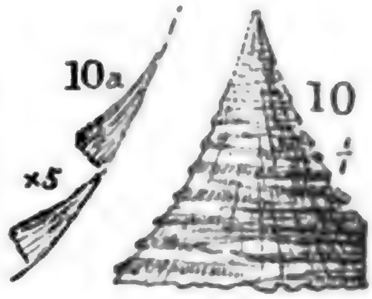

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W. S. Gresley del. et photogr.

CONE-IN-CONE.

but giving prominence to the curved ridges of clayey material sticking out around the rim of the cone in a manner suggestive of vertical or lateral squeezes amongst the cones.

Fig. 14. Transverse section (polished surface) of an abnormal development of the horizontal dark clayey rings of figs. 11–13, showing a fibrous or laminated structure. From the Lower Productive Coal Measures, Beaver Falls, Western Pennsylvania.

Fig. 15. Slightly magnified portion of a micro-slide of Portage cone-in-cone (inverted layer), exhibiting miniature faulting in a dark layer of sediment passing through the conic cake. The dark spots are various portions of the same form as that shown in Pl. XXXV. fig. 24. From Northeast, Pennsylvania.

Fig. 16. Much reduced drawing of parts of three heights of inverted cone-in-cone affected by a local swelling (a concretionary ridge?) of the central or nucleal stratum of the conic mass of which they form a portion. This also shows slight faulting of the cones, clearly a result of lateral pressure in connexion with the swelling above. Reduced about 8 times.

Fig. 17. Cone-in-cone, with truncated apices.

Fig. 18. Conic scales, somewhat distorted, with their apices bent backward and disarranged.

Fig. 19. Horn-shaped cone-in-cone, with slickensided surfaces.

Fig. 20. View of a complete cone, looking at its apex, showing the arrangement of the pointed ends of the component conic scales forming the apex.

Fig. 21. Markings on the polished surface of a transverse section of a good cone, about ½ inch from the base of the cone. This shows the component conic structure and some of the dark specks (see Pl. XXXV. fig. 24).

Fig. 22. Perspective view of a bit of argillaceous shale, on one flat surface of which a singular concentrically-arranged scalariform structure of the same shale was revealed. This may possibly represent the impression of the base-surface of part of a layer of cone-in-cone.

Fig. 23. Reproduction from a photograph of part of two inverted conic cakes seen in cross fracture. The upper layer of cones is much confused, crumpled and slickensided. A thin band of calcareous sandstone separates the two layers of cones.

GENERAL INDEX

TO

THE QUARTERLY JOURNAL

AND

PROCEEDINGS OF THE GEOLOGICAL SOCIETY.

[The Fossils of which the names are printed in italics are figured.]

END OF VOL. L.

Printed by TAYLOR AND FRANCIS, Red Lion Court, Fleet Street.

PROCEEDINGS

OF THE

GEOLOGICAL SOCIETY OF LONDON.

SESSION 1893–94.

November 8th, 1893.

W. H. Hudleston, Esq., M.A., F.R.S., President, in the Chair.

Louis Henry Cooke, Esq., Assoc.R.S.M., Assistant to the Professor of Mining at the Royal College of Science, Loddington, Kettering, and Richard A. S. Redmayne, Esq., Harewood, Gateshead-on-Tyne, were elected Fellows; and Monsieur Ed. Rigaux, Boulogne-sur-Mer, was elected a Foreign Correspondent of the Society.

The List of Donations to the Library was read.

Prof. J. W. Judd made a few remarks in explanation of the specimen exhibited by him.

The following communications were read:—

1. 'The Geology of Bathurst, New South Wales.' By W. J. Clunies Ross, Esq., B.Sc., F.G.S.

2. 'The Geology of Matto Grosso (particularly of the Region drained by the Upper Paraguay).' By J. W. Evans, D.Sc., LL.B., F.G.S.

3. 'Notes on the Occurrence of Mammoth-remains in the Yukon District of Canada and in Alaska.' By George M. Dawson, C.M.G., LL.D., F.R.S., F.G.S.

The following specimens were exhibited:—

Sections and rock-specimens from the District of Bathurst, New South Wales, exhibited by J. T. Day, Esq., F.G.S., in illustration of Mr. W. J. Clunies Ross's paper.

Sections and rock-specimens from Matto Grosso, exhibited by J. W. Evans, D.Sc., LL.B., F.G.S., in illustration of his paper.

Examples of Composite 'Contemporaneous' Veins (Aplite) traversing the Granite of Beinn Cruachan, Argyllshire, exhibited by Prof. J. W. Judd, F.R.S., V.P.G.S.

Specimens of Cassiterite, Antimonite, Zaratite, and Phacolite, from Victoria, Australia, exhibited by F. Danvers Power, Esq., F.G.S.

Specimen from Goathurst Common, near Ide Hill, Kent, exhibited by the Rev. R. Ashington Bullen, B.A., F.G.S.

November 22nd, 1893.

W. H. Hudleston, Esq., M.A., F.R.S., President, in the Chair.

George Henry Hill, Esq., M.Inst.C.E., 3 Victoria Street, S.W., and Albert Chambers, Albert Square, Manchester, was elected a Fellow of the Society.

The List of Donations to the Library was read.

The Secretary announced that Prof. J. Prestwich, D.C.L., F.R.S., had presented a large framed photograph of himself to the Society.

The following communications were read :—

1. 'The Basic Eruptive Rocks of Gran.' By W. C. Brögger, Ord. Prof. of Min. and Geol. in the University of Christiania, For. Memb. Geol. Soc.

2. 'On the Sequence of Perlitic and Spherulitic Structures (a Rejoinder to Criticism).' By Frank Rutley, Esq., F.G.S.

3. 'Enclosures of Quartz in Lava of Stromboli, etc., and the Changes in Composition produced by them.'[1] By Prof. H. J. Johnston-Lavis, M.D., F.G.S.

[Abstract.]

The Author describes the existence of enclosures of quartz in a lava-stream at the Punta Petrazza on the east side of Stromboli, and also in the rock of the neck of Strombolicchio. He describes the effects of the rocks upon the enclosures, concluding that the quartz has undergone fluxion but not fusion, and has supplied silica to the containing lavas, thus causing an increase in the amount of pyroxene and a diminution in the amount of magnetite in the portions of those lavas that surround the inclusions and raising the percentage of silica. He suggests that such a process at greater depths and higher temperature may, under certain conditions, convert a basic rock into a more acid one, so that possibly the andesite of Strombolicchio may have been of basaltic character at an earlier period of its progress towards the surface. He offers the suggestion that other rocks or minerals once associated with the quartz have been assimilated by the magma.

[1] This paper has been withdrawn by permission of the Council.

DISCUSSION.

The PRESIDENT and Prof. JUDD spoke.

The following specimens were exhibited:—

Rock-specimens exhibited by Prof. W. C. Brögger, For.Memb.G.S., in illustration of his paper.

Specimens and microscope-sections, exhibited by Frank Rutley, Esq., F.G.S., in illustration of his paper.

Specimens and microscope-sections, exhibited by Prof. H. J. Johnston-Lavis, M.D., F.G.S., in illustration of his paper.

A new mineral found at Greenbushes, Bunbury, Western Australia, associated with alluvial Cassiterite, exhibited (with analysis) by F. Danvers Power, Esq., F.G.S.

December 6th, 1893.

W. H. HUDLESTON, Esq., M.A., F.R.S., President, in the Chair.

Henry Dyke Acland, Esq., Great Malvern; John Forbes Bryant, Esq., B.A., Clare College, Cambridge; David Draper, Esq., Lennoxton, Newcastle, Natal; Gavin H. Jack, Esq., 10 Pennel Square, Pontypridd, South Wales; Septimus Heslop, Esq., Asansol, E.I.R., India; James Henry Howarth, Esq., The Crescent, Newton Park, Leeds; William Humble, Esq., Wickham, Newcastle, New South Wales; Arthur Walton Rowe, Esq., M.S., M.B., M.R.C.S., 1 Cecil Street, Margate; Joseph Scott, Esq., Newcastle Street, Stockton, New South Wales; William Simpson, Esq., Savile Mount, Halifax; Victor Streich, Esq., care of Messrs. Harrold Brothers, Adelaide, South Australia; John James Turnbull, Esq., Giridih, E.I.R., Bengal, India; and Albert Wilmore, Esq., Trawden, Colne, Lancashire, were elected Fellows of the Society.

The List of Donations to the Library was read.

In explanation of a specimen exhibited by F. B. Du Pre, Esq., M.A., F.G.S., Mr. HORACE W. MONCKTON remarked that the specimen came from a dyke in the Brockwell Seam at the Croxdale Colliery, about 2 miles south of Durham, depth 80 fathoms. This is probably the dyke described by Mr. Teall as 2 miles north of the Hett Dyke ('Brit. Petrography,' p. 202). The greater part of the rock is composed of lath-shaped plagioclase-felspar; the remainder appears to be augite, or change-products after augite, and iron oxide.

The following communications were read:—

1. 'The Purbeck Beds of the Vale of Wardour.' By the Rev. W. R. Andrews, M.A., F.G.S., and A. J. Jukes-Browne, Esq., B.A., F.G.S.

2. 'On a Picrite and other associated Rocks at Barnton, near Edinburgh.' By Horace W. Monckton, Esq., F.L.S., F.G.S.

3. 'On a Variety of *Ammonites* (*Stephanoceras*) *subarmatus*, Young, from the Upper Lias of Whitby.' By Horace W. Monckton, Esq., F.L.S., F.G.S.

[Abstract.]

The Author exhibited an ammonite found by himself in 1874 near Sandsend, 3 miles north-west of Whitby. He thinks it was not actually *in situ*, but lying with a number of nodules on the floor of an old alum-pit, although he has no doubt that it is from the Alum Shale of the Upper Lias. A peculiar arrangement of the costæ as they cross the siphonal area distinguishes the specimen from other Whitby ammonites known to the Author. It bears a strong resemblance to a shell figured as *A. subarmatus* by D'Orbigny, 'Terr. Jurass.,' pl. lxxvii., but is unlike the figures of that species given by other authors.

Discussion.

Prof. J. F. Blake said that the ammonite in question seemed nothing unusual. It would be included in the varieties or mutations of *subarmatus*, the genus of which was not *Stephanoceras*.

Mr. George C. Crick also spoke.

The Author, in reply, pointed out that he only claimed his fossil to be a variety, not a new species; and if a variety, it must be a variety of some species. He thought it was less unlike *A. subarmatus* than other Liassic species. In any case, it was, he thought, the *A. subarmatus* of D'Orbigny, and in assigning that species to *Stephanoceras* he had simply followed Dr. Wright.

In addition to the specimen described on the preceding page, the following were exhibited:—

Rock-specimens from Barnton, near Edinburgh; and specimen of *Ammonites subarmatus*, var., from the Lias of Whitby, exhibited by Horace W. Monckton, Esq., F.L.S., F.G.S., in illustration of his papers.

Specimens of Scottish Granite, exhibited by Horace W. Monckton, Esq., F.L.S., F.G.S.

December 20th, 1893.

W. H. Hudleston, Esq., M.A., F.R.S., President, in the Chair.

Arthur Hassam, Esq., Waverley House, Fenton, Stoke-on-Trent; Robert Ludwig Mond, Esq., M.A., F.R.S.E., F.C.S., The Poplars, 20 Avenue Road, Regent's Park, N.W.; and Llewellyn Treacher, Esq., Somercroft, Twyford, Berkshire, were elected Fellows; Dr. E. Mojsisovics von Mojsvár, Vienna, and Dr. A. G. Nathorst, Stockholm, Foreign Members; and Dr. S. L. Törnquist, Lund, a Foreign Correspondent of the Society.

The List of Donations to the Library was read.

The following communications were read:—

1. 'On the Stratigraphical, Lithological, and Palæontological Features of the Gosau Beds of the Gosau District, in the Austrian Salzkammergut.' By Herbert Kynaston, Esq., B.A. (Communicated by J. E. Marr, Esq., M.A., F.R.S., Sec.G.S.)

2. 'Artesian Boring at New Lodge, near Windsor Forest, Berks.' By Prof. Edward Hull, M.A., LL.D., F.R.S., F.G.S.

3. 'Boring on the Booysen Estate, Witwatersrand.' By D. Telford Edwards, Esq. (Communicated by the President.)

[Abstract.]

The borehole is situated about 2 miles from Johannesburg, and about 5000 feet due south of the Wemmer Gold Mining Company's main hauling shaft. It was carried to a depth of 1020 feet. The measures passed through were sandstones and quartzites, with banks of conglomerates, the so-called 'reefs.' A group of these conglomerates, known as the Bird Reef series, was cut between the depths of 470 and 970 feet; it contained eighteen beds of conglomerate, two of which, at the respective depths of 536 and 636 feet, were 22 and 26 feet in thickness, and yielded no trace of gold. The remainder varied from 2 feet to 5 inches in thickness; in eight of them traces of gold were detected, and all were mineralized with iron pyrites. The dip varied from 32° to 35° down to a depth of 835 feet; here it seemed to decrease for a while to 20°, but lower down it increased to 32° and 33°.

[The lower part of the boring passed through country rock (quartzite).—Feb. 5th, 1894.]

The following specimens were exhibited:—

Specimens of rocks from a deep boring and other workings in the neighbourhood of Johannesburg, South African Republic, collected by H. C. Simpson, Esq. Exhibited by W. J. Lewis Abbott, Esq., F.G.S.

January 10th, 1894.

W. H. Hudleston, Esq., M.A., F.R.S., President, in the Chair.

Walter Cleeve Edwards, Esq., Assoc.M.Inst.C.E., Midland Railway, Greymouth, New Zealand; Thomas Walker Fowler, Esq., Assoc.M.Inst.C.E., Modern Chambers, 317 Collins Street, Melbourne, Victoria; Edmund William Janson, Esq., B.A., Trelowarren Street, Camborne; and Thomas Escolme Storey, Esq., Weston Coyney Hall, Longton, Staffordshire, were elected Fellows of the Society.

The following Fellows, nominated by the Council, were elected Auditors of the Society's Accounts for the preceding year:—H. W. MONCKTON, Esq., F.L.S., and J. HOPKINSON, Esq., F.L.S.

The List of Donations to the Library was read.

The following communications were read:—

1. 'On the Rhætic and some Liassic Ostracoda of Britain.' By Prof. T. Rupert Jones, F.R.S., F.G.S.

2. 'Leigh Creek Jurassic Coal-Measures of South Australia: their Origin, Composition, Physical and Chemical Characters; and Recent Subaerial Metamorphism of Local Superficial Drift.' By James Parkinson, Esq., F.G.S., F.C.S.

[Abstract.]

This paper contains an account of the lignitic coal of Leigh Creek and associated rocks. Analyses are given, as illustrating comparisons between the Leigh Creek coal and Jurassic and other coal-bearing rocks found elsewhere. The Author discusses the origin of the Leigh Creek deposits, and describes certain peculiarities noticeable in the superficial materials, which he discusses in another paper.

DISCUSSION.

The PRESIDENT remarked that the meeting was taken at a disadvantage, since it was probable that no one knew the district, and, moreover, there was no one present to demonstrate the miscellaneous collection on the table which was supposed to illustrate the paper. It would seem that the Author takes it for granted that the Leigh Creek beds are of Jurassic age, and no one present could deny it, although he (the President) was not aware that the paper contained any palæontological evidence to that effect. The Author appears to be attacking somebody—probably a Government surveyor. On the whole, one would say that he was more of a chemist than a geologist. In concluding his remarks, the President called attention to an analysis of South Australian crocidolite, as compared with specimens from Africa.

Mr. A. R. BROWNE regretted that the Author had not given any idea of the commercial value of the deposit, and pointed out that the question was one of great importance in South Australia, as on it depended, amongst other things, to a great extent the working of many large mineral deposits in the vicinity. He had visited the field and made analyses of the coal, which he found to be very similar to that of the Tertiary deposits near Teplitz in Bohemia.

3. 'Physical and Chemical Geology of the Interior of Australia: Recent Subaerial Metamorphism of Eolian Sand at ordinary atmospheric temperature into Quartz, Quartzite, and other stones.' By James Parkinson, Esq., F.G.S., F.C.S.

[Abstract.]

South of the Flinders Range fragments of stone of all sizes are found on the ground, the origin of which the Author discusses. He maintains that they were formed by subaerial metamorphism of Eolian deposits.

Discussion.

The President said that this was rather a startling communication, though he was by no means prepared to say there was nothing in it. He alluded to the well-known effects of hot climates in this respect.

Mr. R. D. Oldham said that a quartzitic induration at the surface, similar to that described by the Author, was noticeable in the more arid parts of India. In the desert of Western Rajputana he had found the soft Upper Jurassic sandstones locally indurated into hard glassy quartzites, and the change appeared to be superficial. In the diamond mines of Southern India the superficial nature of the alteration was evident, for the miners, after penetrating the quartzitic rock near the surface, found the deeper-seated portions to be soft and easily worked. The cement was in every case siliceous.

Prof. T. Rupert Jones remarked, with regard to the rough, cylindrical holes traversing some of the quartzitic rock in different directions, that they reminded him of similar cavities which he had seen in septaria of the London Clay; and were probably due to the imbedment of tough, wrinkled stems of long seaweeds or other rope-like plants.

Dr. Henry Woodward drew attention to the collection sent home by Mr. Parkinson, and suggested that the cavities in sandstone, referred to by the Author, may have been formed by stems of plants which have since decayed, or they may be annelid tubes. He pointed out certain casts of bodies resembling the so-called 'fucoid' (*Harlania Halli*) from Niagara Falls, also met with on the Gold Coast, W. Africa, and in the Mokattam Quarries, near Cairo. These are probably all due to annelids.

Mr. Marr, Dr. G. J. Hinde, and Mr. E. T. Newton also spoke.

The following specimens were exhibited:—

Entomostraca from the Rhætic and Lower Lias of Warwickshire, Gloucestershire, etc., exhibited by the Rev. P. B. Brodie, M.A., F.G.S., the Rev. H. H. Winwood, M.A., F.G.S., Edw. Wilson, Esq., F.G.S., W. Cunnington, Esq., F.G.S., and Prof. T. Rupert Jones, F.R.S., F.G.S., in illustration of the paper read by the last-named.

Specimens exhibited by James Parkinson, Esq., F.G.S., F.C.S., in illustration of his papers.

January 24th, 1894.

W. H. Hudleston, Esq., M.A., F.R.S., President, in the Chair.

Herbert Kynaston, Esq., B.A., The College, Durham; James Francis Markes, Esq., 31 Queen Street, Melbourne, Victoria; Henry Preston, Esq., Hawthornden Villa, Grantham; and George Thurland Prior, Esq., M.A., 50 Munster Road, Fulham, S.W., were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communications were read:—

1. 'The Ossiferous Fissures in the Valley of the Shode, near Ightham, Kent.' By W. J. Lewis Abbott, Esq., F.G.S.

2. 'The Vertebrate Fauna collected by Mr. Lewis Abbott from the Fissure near Ightham, Kent.' By E. T. Newton, Esq., F.R.S., F.G.S.

The following specimens were exhibited:—

Specimens of the Vertebrate Fauna, etc., from the Fissure near Ightham, Kent, exhibited by Messrs. W. J. Lewis Abbott, F.G.S., and E. T. Newton, F.R.S., F.G.S., in illustration of their papers.

February 7th, 1894.

W. H. Hudleston, Esq., M.A., F.R.S., President, in the Chair.

Alfred Alcock, M.B., Surgeon-Captain I.M.S., Superintendent of the Indian Museum, Calcutta, and Professor of Zoology in the University of Calcutta, Calcutta, India; William Wickham King, Esq., Pedmore House, near Stourbridge; and Samuel Sydney Platt, Esq., Assoc.M.Inst.C.E., 14 King Street South, Rochdale, were elected Fellows of the Society.

The List of Donations to the Library was read.

Mr. C. J. Alford, F.G.S., in explanation of specimens of auriferous rocks from Mashonaland exhibited by him, stated that several of them were vein-quartz occurring as segregations in the slates, generally forming veins between the cleavage-planes. Another specimen was a mass of chromate of lead, with pyromorphite and other lead minerals, occurring in masses in decomposed and dislocated talcose slate in the Penhalonga Mine near Umtali, and probably resulting from the alteration of masses of galena by weathering,

as a broken vein of galena was found in close proximity. This crocoisite was supposed to be a somewhat rare mineral, but he had found it and also the native red oxide, minium, in several places in South Africa. The most interesting specimen was, however, a mass of diorite showing visible gold throughout the rock, an assay of which gave upwards of 130 ounces of gold per ton. From information obtained from the prospector who made the discovery, he gathered that the deposit was a dyke of diorite running for a considerable distance, about 8 feet in width, flanked on one side by granite and on the other by slates. There were extensive ancient workings extending to a depth of about 60 feet, and the prospecting shafts had not gone much below that depth, so not much information was obtainable at present. The diorite showed a development of epidote, but little or no quartz; and the gold appeared to enter in an extraordinary manner into all of the composing minerals. Mr. Alford hoped, after his next visit to Mashonaland, to be in a position to lay before the Society more definite information regarding these interesting rocks.

The following communications were read:—

1. 'On some cases of the Conversion of Compact Greenstones into Schists.' By Prof. T. G. Bonney, D.Sc., LL.D., F.R.S., F.G.S.

2. 'The Waldensian Gneisses and their Place in the Cottian Sequence.' By J. Walter Gregory, D.Sc., F.G.S.

In addition to the specimens described by Mr. C. J. Alford, the following were exhibited:—

Rock-specimens and microscope-sections, exhibited by Prof. T. G. Bonney, D.Sc., LL.D., F.R.S., F.G.S., in illustration of his paper.

Rock-specimens and microscope-sections, exhibited by Dr. J. W. Gregory, F.G.S., in illustration of his paper.

A series of Flint Implements from Broom Ballast-Hole, Hawkchurch, Devon, exhibited by the Rev. R. Ashington Bullen, B.A., F.G.S.

ANNUAL GENERAL MEETING,

February 16th, 1894.

W. H. Hudleston, Esq., M.A., F.R.S., President, in the Chair.

Report of the Council for 1893.

In congratulating the Fellows on the prosperous condition of the Society's finances, the Council desire at the same time to draw attention to the fact that the decrease in the number of Fellows, which began to make itself apparent in 1892, has continued during 1893.

The number of Fellows elected into the Society in that year was 42, of whom 33 paid their fees before the end of 1893, making, with 6 previously elected Fellows who paid their fees in 1893, a total accession in the course of the twelvemonth of 39 Fellows.

During the same period, however, there was a total loss of 85 Fellows—42 by death, 16 by resignation, 16 removed from the list for non-payment of their Annual Contributions, and 11 (9 of whom were non-Contributors and 2 were Compounders) removed from the list after having remained thereon for many years without any known address.

The actual decrease in the number of Fellows is, therefore, 46.

Of the 42 Fellows deceased, 10 were Compounders, 24 were Contributing Fellows, and 8 were non-Contributing Fellows.

On the other hand, in the twelvemonth under review, 6 Fellows compounded for their Annual Contributions.

From the above figures it will be gathered that the actual decrease in the number of Contributing Fellows is 23, making a total of 873 Contributing Fellows, as compared with 896 at the end of the previous year, and 904 at the end of 1891. In calculating this decrease, the 11 removed from the list for want of addresses are, of course, not included.

The total number of Fellows, Foreign Members, and Foreign Correspondents, which at the end of 1891 was 1418, and at the end of 1892 was 1400, stood at 1353 on December 31st, 1893.

At the end of 1892 there was 1 vacancy in the list of Foreign Members. During the year which has just elapsed the Society has lost by death 3 Foreign Members and 3 Foreign Correspondents.

These vacancies were partly filled by the election of 4 Foreign Members and 5 Foreign Correspondents, but at the end of 1893 there were still 2 vacancies in the list of Foreign Correspondents.

The Society's Income and Expenditure in the year under review may be summarized as follows:—

The total Receipts amounted to £2750 18*s.* 10*d.*, being £205 4*s.* 6*d.* more than the estimated Income for 1893. On the other hand, the total Expenditure during that year (leaving out of account the sum of £502 15*s.* 3*d.* expended in the purchase of £300 London, Brighton, and South Coast Railway 5°/₀ Consolidated Preference Stock) amounted to £2204 17*s.* 6*d.*, being less by £258 4*s.* than the estimated Expenditure for 1893. The actual excess of Receipts over current Expenditure in that year was £546 1*s.* 4*d.*

The Council are glad to report that the Invested Funds of the Society have now reached the sum of £10,729 11*s.*, and they feel that the time has arrived when the question of safeguarding by investment the interests of Compounders may be reopened.

It may be mentioned here that the London and North-western Railway Company, having obtained the necessary powers, converted their 4°/₀ Debenture Stock (in which the Murchison Geological Fund was invested) into a 3°/₀ similar stock, at the rate of £133 6*s.* 8*d.* for every £100 of the former. A small amount was expended out of the Society's general funds to make up an even £, and the amount of Stock now held for the Murchison Trust Account is £1334.

The Council have pleasure in announcing the completion of Volume XLIX. and the commencement of Volume L. of the Society's Journal. In the preface to the first volume of the Journal, issued in 1845, the hope was expressed that here was the commencement of a series extending over many years. That hope has been fulfilled, and it will be the endeavour, as it is the desire, of the Council to maintain in the future the same high standard as that which has distinguished the Society's Journal during its first half-century.

The following awards of Medals and Memorial Funds have been made by the Council:—

The Wollaston Medal is awarded to Geheimrath Professor Karl Alfred von Zittel, For.Memb.G.S., in recognition of the important services rendered by him to Geological Science, especially in the department of Palæontology.

The Murchison Medal, together with a sum of Ten Guineas from the Proceeds of the Fund, is awarded to Mr. W. Talbot Aveline, F.G.S., in recognition of the value of his work amongst the ancient rocks of the British Isles.

The Lyell Medal, and a sum of Forty-six Pounds from the Proceeds of the Fund, is awarded to Professor John Milne, F.R.S., in testimony of appreciation of his investigations in Seismology.

The Balance of the Proceeds of the Wollaston Donation Fund is awarded to Mr. Aubrey Strahan, M.A., F.G.S., in token of appreciation of his work among the stratified rocks of England and Wales, and for the purpose of assisting him in further researches.

The Balance of the Proceeds of the Murchison Geological Fund is awarded to Mr. George Barrow, F.G.S., in recognition of the value of his work among the older rocks of Scotland, and in order to aid him in the further prosecution of his investigations.

The Balance of the Proceeds of the Lyell Geological Fund is awarded to Mr. William Hill, F.G.S., as a testimony of the value of his work among the Cretaceous rocks, and to aid him in further researches.

From the Proceeds of the Barlow-Jameson Fund a sum of Twenty-five Pounds is awarded to Mr. Charles Davison, M.A., in token of appreciation of his work in Seismology, and in order to aid him in further investigations.

Report of the Library and Museum Committee for 1893.

Library.

Your Committee have great pleasure in announcing that many valuable additions have been made to the Library during the past year, both by donation and by purchase.

By Donation the Library has received about 183 Volumes of separately published works and Survey Reports, 221 Pamphlets, and 248 Volumes and 31 detached Parts of the publications of various Societies. Besides these, 16 Volumes of Newspapers have been received. The total addition to the Society's Library by donation amounts, therefore, to 447 Volumes, 31 Parts, and 221 Pamphlets. Moreover, 199 Sheets of Maps and Sections have been presented to the Library, and the Society may be congratulated on the fact that its collection of the one-inch maps of H.M. Geological Survey is now as nearly complete as possible.

The Books and Maps which have just been enumerated were the gift of 114 Personal Donors, 23 Editors or Publishers of Periodicals, 216 Societies, and 36 Survey Departments and other Public Bodies —the total number of Donors being 389.

By Purchase, on the recommendation of the Standing Library Committee, the Society's Library has been enriched by the addition of 84 Volumes of separately published works, 36 Volumes and 44 Parts of works published serially, and 31 Sheets of Maps.

It is a matter of satisfaction to your Committee that further progress has been made during the twelvemonth under review towards completing long-standing deficiencies in the sets of serials in the Library.

Among the sets which have been completed by donation from the respective Institutions are the Transactions of the American Institute of Mining Engineers, the Bulletin of the Essex Institute and Memoirs of the Peabody Academy, and the Proceedings of the Dorset Natural History and Antiquarian Field Club. Among the sets which have been completed, or nearly completed, by purchase are the Reports of the Arkansas and Illinois Geological Surveys, and the Transactions of the Californian Academy of Science. Moreover, your Committee recommended the purchase of a fine copy of Sowerby's 'Mineral Conchology,' in seven volumes (as originally issued).

The total amount expended on the Society's Library during 1893 is as follows :—

	£	s.	d.
Books, Periodicals, etc., purchased	108	18	2
Cost of Binding	15	1	7
Cards for Map Catalogue	1	0	0
Total	£224	19	9

A new Manuscript Card Catalogue of the Geological Maps and Sections in the Library has been commenced, and will probably be completed early in the present year.

The Society's collection of the portraits of eminent geologists has been enriched by the donation from Professor Prestwich of a large framed photograph of himself.

Museum.

No additions have been made to the collections during the past year. The work of labelling in a distinctive manner and registering the type- and other important specimens has been continued by Mr. C. Davies Sherborn. During 1893 he went through 138 drawers of specimens.

The expenditure on the Museum amounted to £16 9*s*. 3*d*., comprising the following items :—

	£	s.	d.
Special work at the Museum	15	0	0
Sundries	1	9	3
	£16	9	3

COMPARATIVE STATEMENT OF THE NUMBER OF THE SOCIETY AT THE CLOSE OF THE YEARS 1892 AND 1893.

	Dec. 31, 1892.		Dec. 31, 1893.
Compounders	311	......	305
Contributing Fellows	896	......	873
Non-contributing Fellows	114	......	97
	1321		1275
Foreign Members	39	......	40
Foreign Correspondents	40	......	38
	1400		1353

Comparative Statement explanatory of the Alterations in the Number of Fellows, Foreign Members, and Foreign Correspondents at the close of the years 1892 *and* 1893.

Number of Compounders, Contributing and Non-contributing Fellows, December 31st, 1892			1321
Add Fellows elected during the former year and paid in 1893			6
Add Fellows elected and paid in 1893			33
			1360
Deduct Compounders deceased		10	
Contributing Fellows deceased		24	
Non-contributing Fellows deceased		8	
Contributing Fellows resigned		16	
Compounders removed		2	
Contributing Fellows removed		16	
Non-contributing Fellows removed		9	
		—	85
			1275
Number of Foreign Members and Foreign Correspondents, December 31st, 1892		79	
Deduct Foreign Members deceased	3		
Foreign Correspondents deceased	3		
Foreign Correspondents elected Foreign Members	4		
	—	10	
		69	
Add Foreign Members elected		4	
Foreign Correspondents elected		5	
		—	78
			1353

Deceased Fellows.

Compounders (10).

Austin, C. E., Esq.
Becher, H. M., Esq.
Davis, J. W., Esq.
Leslie, A., Esq.
Marshall, A., Esq.
Masey, T. A., Esq.
Potter, W. A., Esq.
St. Oswald, Lord.
Tyndall, Prof. J.
Woodd, C. H. L., Esq.

Resident and other Contributing Fellows (24).

Anderson, Sir J.
Blanford, H. F., Esq.
Burnett, R. T., Esq.
Chaplin, J. C., Esq.
Cheetham, W., Esq.
Crosskey, Rev. Dr. J.
Dahll, T., Esq.
Elliot, Sir G.
Hawksley, T., Esq.
Head, J. W., Esq.
Hewitt, J. R., Esq.
Hodges, E., Esq.
Homer, C. J., Esq.
Luxmoore, E. B., Esq.
Millie, J., Esq.
Northbourne, Lord.
Parry, T. S., Esq.
Paterson, J., Esq.
Shrubsole, G. W., Esq.
Smith, S. J., Esq.
Spencer, J., Esq.
Taunton, J. H., Esq.
Tremenheere, H. S., Esq.
Yockney, S. H., Esq.

Non-contributing Fellows (8).

Blomefield, Rev. L.
Charlesworth, E., Esq.
Colquhoun, J., Esq.
Cooksey, J., Esq.
Denton, J. B., Esq.
Elphinstone, Sir H.
Fletcher, Col. T. W.
Pritchard, Rev. C.

Foreign Members (3).

Keyserling, Count A. von.
Kokscharow, Maj.-Gen. N. von.
Stur, Dr. D.

Foreign Correspondents (3).

Lossen, Prof. K. A.
Senft, Dr. F.
Vilanova y Piera, Prof. J.

Fellows Resigned (16).

Bidder, P. B., Esq.
Collins, H. R., Esq.
Crimp, W. S., Esq.
Floyer, E. A., Esq.
Fordham, H. G., Esq.
Hardern, Rev. T. B.
Mackenzie, G. W., Esq.
Myhill, C., Esq.
North, S. W., Esq.
Price, T. J., Esq.
Sleeman, Rev. P. R.
Spencer, J. P., Esq.
Sugg, H., Esq.
Thomas, G. F., Esq.
Thompson, C. G., Esq.
Yeats, Dr. J.

Fellows Removed (27).

Butler, C. A. V., Esq.
Cairnes, E. M., Esq.
*Calder, J., Esq.
Cheadle, R. W., Esq.
Clarke, A. W., Esq.
Couchman, Lieut.-Col. T.
*Cunningham, G., Esq.
*Dickson, J., Esq.
Diggens, J., Esq.
Dobson, A. D., Esq.
*Even, J. B., Esq.
Griffiths, G. S., Esq.
*Hare, J., Esq.
*Holl, W., Esq.
*Hunter, W. P., Esq.
Jones, D. W., Esq.
Kekewich, G. O., Esq.
*Laing, J. T., Esq.
Maybury, Dr. A. C.
*Mornay, A. F., Esq.
O'Donoghue, J., Esq.
*Robinson, A., Esq.
Skertchly, S. B. J., Esq.
*Smith, H., Esq.
Stroud, Dr. J.
Thoreau, G. A. H., Esq.
Wonnacott, J., Esq.

* Removed from the list after having remained thereon for many years without any known address.

The following Personages were elected from the List of Foreign Correspondents to fill the vacancies in the List of Foreign Members during the year 1893:—

Professor Waldemar Christofer Brögger, of Christiania.
Monsieur Auguste Michel-Lévy, of Paris.
Doctor Edmund Mojsisovics von Mojsvár, of Vienna.
Doctor Alfred Gabriel Nathorst, of Stockholm.

The following Personages were elected Foreign Correspondents during the year 1893:—

Professor Marcel Bertrand, of Paris.
Professor Aléxis Pavlow, of Moscow.
Monsieur Ed. Rigaux, of Boulogne-sur-Mer.
Doctor Sven Leonhard Törnquist, of Lund.
Doctor Charles Abiathar White, of Washington, D.C.

After the Reports had been read, it was resolved:—

That they be received and entered on the Minutes of the Meeting, and that such parts of them as the Council shall think fit be printed and circulated among the Fellows.

It was afterwards resolved:—

That the thanks of the Society be given to W. H. Hudleston, Esq., retiring from the office of President.

That the thanks of the Society be given to Sir Archibald Geikie and Dr. H. Woodward, retiring from the office of Vice-Presidents.

That the thanks of the Society be given to Prof. J. F. Blake, Prof. T. G. Bonney, R. Etheridge, Esq., Sir Archibald Geikie, and Dr. H. Hicks, retiring from the Council.

After the Balloting-glasses had been duly closed, and the Lists examined by the Scrutineers, the following gentlemen were declared to have been duly elected as the Officers and Council for the ensuing year:—

OFFICERS.

PRESIDENT.

Henry Woodward, LL.D., F.R.S.

VICE-PRESIDENTS.

Prof. A. H. Green, M.A., F.R.S.
G. J. Hinde, Ph.D.
Prof. J. W. Judd, F.R.S.
R. Lydekker, Esq., B.A.

SECRETARIES.

J. E. Marr, Esq., M.A., F.R.S.
J. J. H. Teall, Esq., M.A., F.R.S.

FOREIGN SECRETARY.

J. W. Hulke, Esq., F.R.S.

TREASURER.

Prof. T. Wiltshire, M.A., F.L.S.

COUNCIL.

H. Bauerman, Esq.
W. T. Blanford, LL.D., F.R.S.
Sir John Evans, K.C.B., LL.D., F.R.S., F.L.S.
Prof. A. H. Green, M.A., F.R.S.
J. W. Gregory, D.Sc.
Alfred Harker, Esq., M.A.
G. J. Hinde, Ph.D.
T. V. Holmes, Esq.
W. H. Hudleston, Esq., M.A., F.R.S., F.L.S.
J. W. Hulke, Esq., F.R.S.
Prof. J. W. Judd, F.R.S.
Prof. C. Lapworth, M.A., F.R.S.
R. Lydekker, Esq., B.A.
Lieut.-General C. A. McMahon.
J. E. Marr, Esq., M.A., F.R.S.
H. W. Monckton, Esq., F.L.S.
Clement Reid, Esq., F.L.S.
F. Rutley, Esq.
J. J. H. Teall, Esq., M.A., F.R.S.
Prof. T. Wiltshire, M.A., F.L.S.
Rev. H. H. Winwood, M.A.
Henry Woodward, LL.D., F.R.S.
H. B. Woodward, Esq.

LIST OF
THE FOREIGN MEMBERS
OF THE GEOLOGICAL SOCIETY OF LONDON, IN 1893.

Date of Election.

1848. James Hall, Esq., *Albany, State of New York, U.S.A.*
1851. Professor James D. Dana, *New Haven, Connecticut, U.S.A.*
1853. Count Alexander von Keyserling, *Raykül, Russia.* (*Deceased.*)
1856. Professor Robert Bunsen, For. Mem. R.S., *Heidelberg.*
1857. Professor H. B. Geinitz, *Dresden.*
1867. Professor A. Daubrée, For. Mem. R.S., *Paris.*
1871. Dr. Franz Ritter von Hauer, *Vienna.*
1874. Professor Albert Gaudry, *Paris.*
1875. Professor Fridolin Sandberger, *Würzburg.*
1876. Professor E. Beyrich, *Berlin.*
1877. Dr. Carl Wilhelm Gümbel, *Munich.*
1877. Dr. Eduard Suess, *Vienna.*
1879. Major-General N. von Kokscharow, *St. Petersburg.* (*Deceased.*)
1879. M. Jules Marcou, *Cambridge, U.S.A.*
1879. Dr. J. J. S. Steenstrup, For. Mem. R.S., *Copenhagen.*
1880. Professor Gustave Dewalque, *Liége.*
1880. Baron Adolf Erik Nordenskiöld, *Stockholm.*
1880. Professor Ferdinand Zirkel, *Leipzig.*
1882. Professor Sven Lovén, *Stockholm.*
1882. Professor Ludwig Rütimeyer, *Basel.*
1883. Professor Otto Martin Torell, *Stockholm.*
1884. Professor G. Capellini, *Bologna.*
1884. Professor A. L. O. Des Cloizeaux, For. Mem. R.S., *Paris.*
1884. Professor J. Szabó, *Pesth.*
1885. Professor Jules Gosselet, *Lille.*
1886. Professor Gustav Tschermak, *Vienna.*
1887. Professor J. P. Lesley, *Philadelphia, U.S.A.*
1887. Professor J. D. Whitney, *Cambridge, U.S.A.*
1888. Professor Pierre J. van Beneden, *Louvain.* (*Deceased.*)
1888. Professor Eugène Renevier, *Lausanne.*
1888. Baron Ferdinand von Richthofen, *Berlin.*
1889. Professor Ferdinand Fouqué, *Paris.*
1889. Marquis Gaston de Saporta, *Aix-en-Provence.*
1889. Geheimrath Professor Karl Alfred von Zittel, *Munich.*
1890. Professor Heinrich Rosenbusch, *Heidelberg.*
1890. Herr Dionys Stur, *Vienna.* (*Deceased.*)
1891. Dr. Charles Barrois, *Lille.*
1891. M. Gustave H. Cotteau, *Auxerre.*
1892. Professor Gustav Lindström, *Stockholm.*
1893. Professor Waldemar Christofer Brögger, *Christiania.*
1893. M. Auguste Michel-Lévy, *Paris.*
1893. Dr. Edmund Mojsisovics von Mojsvár, *Vienna.*
1893. Dr. Alfred Gabriel Nathorst, *Stockholm.*

LIST OF

THE FOREIGN CORRESPONDENTS

OF THE GEOLOGICAL SOCIETY OF LONDON, IN 1893.

Date of Election.

1863. Dr. F. Senft, *Eisenach*. (*Deceased.*)
1866. Professor Victor Raulin, *Montfaucon d'Argonne*.
1874. Professor Igino Cocchi, *Florence*.
1874. Dr. T. C. Winkler, *Haarlem*.
1877. Professor George J. Brush, *New Haven, Connecticut, U.S.A.*
1879. M. Édouard Dupont, *Brussels*.
1879. Dr. Émile Sauvage, *Boulogne-sur-Mer*.
1880. Professor Alphonse Renard, *Ghent*.
1881. Professor E. D. Cope, *Philadelphia, U.S.A.*
1882. Professor Louis Lartet, *Toulouse*.
1882. Professor Alphonse Milne-Edwards, *Paris*.
1884. M. Alphonse Briart, *Morlanwelz*.
1884. Professor Hermann Credner, *Leipzig*.
1884. Baron C. von Ettingshausen, *Grätz*.
1886. Professor J. Vilanova y Piera, *Madrid*. (*Deceased.*)
1887. Senhor J. F. N. Delgado, *Lisbon*.
1887. Professor A. Heim, *Zürich*.
1887. Professor A. de Lapparent, *Paris*.
1888. M. Charles Brongniart, *Paris*.
1888. Professor Edward Salisbury Dana, *New Haven, Connecticut, U.S.A.*
1888. Professor Anton Fritsch, *Prague*.
1888. M. Ernest Van den Broeck, *Brussels*.
1889. Professor G. K. Gilbert, *Washington, D.C., U.S.A.*
1889. Dr. Hans Reusch, *Christiania*.
1889. M. R. D. M. Verbeek, *Padang, Sumatra*.
1890. M. Gustave F. Dollfus, *Paris*.
1890. Herr Felix Karrer, *Vienna*.
1890. Professor Adolph von Könen, *Göttingen*.
1890. M. Friedrich Schmidt, *St. Petersburg*.
1891. Señor Don Antonio del Castillo, *Mexico*.
1891. Professor W. Dames, *Berlin*.
1891. Professor Emanuel Kayser, *Marburg*.
1891. Professor Karl August Lossen, *Berlin*. (*Deceased.*)
1892. Professor Johann Lehmann, *Kiel*.
1892. Major John W. Powell, *Washington, D.C., U.S.A.*
1892. Professor George H. Williams, *Baltimore, U.S.A.*
1893. Professor Marcel Bertrand, *Paris*.
1893. Professor Aléxis Pavlow, *Moscow*.
1893. M. Ed. Rigaux, *Boulogne-sur-Mer*.
1893. Dr. Sven Leonhard Törnquist, *Lund*.
1893. Dr. Charles Abiathar White, *Washington, D.C., U.S.A.*

AWARDS OF THE WOLLASTON MEDAL

UNDER THE CONDITIONS OF THE 'DONATION FUND'

ESTABLISHED BY

WILLIAM HYDE WOLLASTON, M.D., F.R.S., F.G.S., ETC.

"To promote researches concerning the mineral structure of the earth, and to enable the Council of the Geological Society to reward those individuals of any country by whom such researches may hereafter be made,"—"such individual not being a Member of the Council."

1831. Mr. William Smith.
1835. Dr. G. A. Mantell.
1836. M. Louis Agassiz.
1837. Capt. T. P. Cautley. Dr. H. Falconer.
1838. Sir Richard Owen.
1839. Professor C. G. Ehrenberg.
1840. Professor A. H. Dumont.
1841. M. Adolphe T. Brongniart.
1842. Baron L. von Buch.
1843. M. Élie de Beaumont. M. P. A. Dufrénoy.
1844. Rev. W. D. Conybeare.
1845. Professor John Phillips.
1846. Mr. William Lonsdale.
1847. Dr. Ami Boué.
1848. Rev. Dr. W. Buckland.
1849. Professor Joseph Prestwich.
1850. Mr. William Hopkins.
1851. Rev. Prof. A. Sedgwick.
1852. Dr. W. H. Fitton.
1853. M. le Vicomte A. d'Archiac. M. E. de Verneuil.
1854. Sir Richard Griffith.
1855. Sir H. T. De la Beche.
1856. Sir W. E. Logan.
1857. M. Joachim Barrande.
1858. Herr Hermann von Meyer. Mr. James Hall.
1859. Mr. Charles Darwin.
1860. Mr. Searles V. Wood.
1861. Professor Dr. H. G. Bronn.
1862. Mr. R. A. C. Godwin-Austen.
1863. Professor Gustav Bischof.
1864. Sir R. I. Murchison.
1865. Dr. Thomas Davidson.
1866. Sir Charles Lyell.
1867. Mr. G. Poulett Scrope.
1868. Professor Carl F. Naumann.
1869. Dr. H. C. Sorby.
1870. Professor G. P. Deshayes.
1871. Sir A. C. Ramsay.
1872. Professor J. D. Dana.
1873. Sir P. de M. Grey Egerton.
1874. Professor Oswald Heer.
1875. Professor L. G. de Koninck.
1876. Professor T. H. Huxley.
1877. Mr. Robert Mallet.
1878. Dr. Thomas Wright.
1879. Professor Bernhard Studer.
1880. Professor Auguste Daubrée.
1881. Professor P. Martin Duncan.
1882. Dr. Franz Ritter von Hauer.
1883. Dr. W. T. Blanford.
1884. Professor Albert Gaudry.
1885. Mr. George Busk.
1886. Professor A. L. O. Des Cloizeaux.
1887. Mr. J. Whitaker Hulke.
1888. Mr. H. B. Medlicott.
1889. Professor T. G. Bonney.
1890. Professor W. C. Williamson.
1891. Professor J. W. Judd.
1892. Baron Ferdinand von Richthofen.
1893. Professor N. S. Maskelyne.
1894. Geheimrath Professor Karl Alfred von Zittel.

AWARDS

OF THE

BALANCE OF THE PROCEEDS OF THE WOLLASTON 'DONATION FUND.'

1831. Mr. William Smith.
1833. Mr. William Lonsdale.
1834. M. Louis Agassiz.
1835. Dr. G. A. Mantell.
1836. Professor G. P. Deshayes.
1838. Sir Richard Owen.
1839. Professor C. G. Ehrenberg.
1840. Mr. J. De Carle Sowerby.
1841. Professor Edward Forbes.
1842. Professor John Morris.
1843. Professor John Morris.
1844. Mr. William Lonsdale.
1845. Mr. Geddes Bain.
1846. Mr. William Lonsdale.
1847. M. Alcide d'Orbigny.
1848. Cape-of-Good-Hope Fossils. M. Alcide d'Orbigny.
1849. Mr. William Lonsdale.
1850. Professor John Morris.
1851. M. Joachim Barrande.
1852. Professor John Morris.
1853. Professor L. G. de Koninck.
1854. Dr. S. P. Woodward.
1855. Drs. G. and F. Sandberger.
1856. Professor G. P. Deshayes.
1857. Dr. S. P. Woodward.
1858. Mr. James Hall.
1859. Mr. Charles Peach.
1860. Professor T. Rupert Jones. Mr. W. K. Parker.
1861. Professor A. Daubrée.
1862. Professor Oswald Heer.
1863. Professor Ferdinand Senft.
1864. Professor G. P. Deshayes.
1865. Mr. J. W. Salter.
1866. Dr. Henry Woodward.
1867. Mr. W. H. Baily.
1868. M. J. Bosquet.
1869. Mr. W. Carruthers.
1870. M. Marie Rouault.
1871. Mr. R. Etheridge.
1872. Dr. James Croll.
1873. Professor J. W. Judd.
1874. Dr. Henri Nyst.
1875. Mr. L. C. Miall.
1876. Professor Giuseppe Seguenza.
1877. Mr. R. Etheridge, Jun.
1878. Professor W. J. Sollas.
1879. Mr. Samuel Allport.
1880. Mr. Thomas Davies.
1881. Dr. R. H. Traquair.
1882. Dr. G. J. Hinde.
1883. Professor John Milne.
1884. Mr. E. Tulley Newton.
1885. Dr. Charles Callaway.
1886. Mr. J. S. Gardner.
1887. Mr. B. N. Peach.
1888. Mr. J. Horne.
1889. Mr. A. Smith Woodward.
1890. Mr. W. A. E. Ussher.
1891. Mr. R. Lydekker.
1892. Mr. O. A. Derby.
1893. Mr. J. G. Goodchild.
1894. Mr. Aubrey Strahan.

AWARDS OF THE MURCHISON MEDAL

AND OF THE

PROCEEDS OF THE 'MURCHISON GEOLOGICAL FUND,'

ESTABLISHED UNDER THE WILL OF THE LATE

SIR RODERICK IMPEY MURCHISON, BART., F.R.S., F.G.S.

"To be applied in every consecutive year in such manner as the Council of the Society may deem most useful in advancing Geological Science, whether by granting sums of money to travellers in pursuit of knowledge, to authors of memoirs, or to persons actually employed in any inquiries bearing upon the science of Geology, or in rewarding any such travellers, authors, or other persons, and the Medal to be given to some person to whom such Council shall grant any sum of money or recompense in respect of Geological Science."

1873. Mr. William Davies. *Medal.*
1873. Professor Oswald Heer.
1874. Dr. J. J. Bigsby. *Medal.*
1874. Mr. Alfred Bell.
1874. Professor Ralph Tate.
1875. Mr. W. J. Henwood. *Medal.*
1875. Professor H. G. Seeley.
1876. Mr. A. R. C. Selwyn. *Medal.*
1876. Dr. James Croll.
1877. Rev. W. B. Clarke. *Medal.*
1877. Professor J. F. Blake.
1878. Dr. H. B. Geinitz. *Medal.*
1878. Professor Charles Lapworth.
1879. Professor F. M'Coy. *Medal.*
1879. Mr. J. W. Kirkby.
1880. Mr. R. Etheridge. *Medal.*
1881. Sir Archibald Geikie. *Medal.*
1881. Mr. F. Rutley.
1882. Professor J. Gosselet. *Medal.*
1882. Professor T. Rupert Jones.
1883. Professor H. R. Göppert. *Medal.*
1883. Mr. John Young.
1884. Dr. H. Woodward. *Medal.*
1884. Mr. Martin Simpson.
1885. Dr. Ferdinand von Römer. *Medal.*
1885. Mr. Horace B. Woodward.
1886. Mr. W. Whitaker. *Medal.*
1886. Mr. Clement Reid.
1887. Rev. P. B. Brodie. *Medal.*
1887. Mr. Robert Kidston.
1888. Professor J. S. Newberry. *Medal.*
1888. Mr. Edward Wilson.
1889. Professor James Geikie. *Medal.*
1889. Professor G. A. J. Cole.
1890. Professor Edward Hull. *Medal.*
1890. Mr. E. Wethered.
1891. Professor W. C. Brögger. *Medal.*
1891. Rev. R. Baron.
1892. Professor A. H. Green. *Medal.*
1892. Mr. Beeby Thompson.
1893. Rev. O. Fisher. *Medal.*
1893. Mr. G. J. Williams.
1894. Mr. W. T. Aveline. *Medal.*
1894. Mr. George Barrow.

AWARDS OF THE LYELL MEDAL

AND OF THE

PROCEEDS OF THE 'LYELL GEOLOGICAL FUND,'

ESTABLISHED UNDER THE WILL AND CODICIL OF THE LATE SIR CHARLES LYELL, Bart., F.R.S., F.G.S.

The Medal "to be given annually" (or from time to time) "as a mark of honorary distinction and as an expression on the part of the governing body of the Society that the Medallist (who may be of any country or either sex) has deserved well of the Science,"—"not less than one third of the annual interest [of the fund] to accompany the Medal, the remaining interest to be given in one or more portions at the discretion of the Council for the encouragement of Geology or of any of the allied sciences by which they shall consider Geology to have been most materially advanced, either for travelling expenses or for a memoir or paper published, or in progress, and without reference to the sex or nationality of the author, or the language in which any such memoir or paper may be written."

1876. Professor John Morris. *Medal.*
1877. Dr. James Hector. *Medal.*
1877. Mr. W. Pengelly.
1878. Mr. G. Busk. *Medal.*
1878. Professor W. Waagen.
1879. Professor Edmond Hébert. *Medal.*
1879. Professor H. A. Nicholson.
1879. Dr. Henry Woodward.
1880. Sir John Evans. *Medal.*
1880. Professor F. A. von Quenstedt.
1881. Sir J. W. Dawson. *Medal.*
1881. Dr. Anton Fritsch.
1881. Mr. G. R. Vine.
1882. Dr. J. Lycett. *Medal.*
1882. Rev. Norman Glass.
1882. Professor Charles Lapworth.
1883. Dr. W. B. Carpenter. *Medal.*
1883. Mr. P. H. Carpenter.
1883. M. E. Rigaux.
1884. Dr. Joseph Leidy. *Medal.*
1884. Professor Charles Lapworth.
1885. Professor H. G. Seeley. *Medal.*
1885. Mr. A. J. Jukes-Browne.
1886. Mr. W. Pengelly *Medal.*
1886. Mr. D. Mackintosh.
1887. Mr. Samuel Allport. *Medal.*
1887. Rev. Osmond Fisher.
1888. Professor H. A. Nicholson. *Medal.*
1888. Mr. A. H. Foord.
1888. Mr. Thomas Roberts.
1889. Professor W. Boyd Dawkins. *Medal.*
1889. M. Louis Dollo.
1890. Professor T. Rupert Jones. *Medal.*
1890. Mr. C. Davies Sherborn.
1891. Professor T. McKenny Hughes. *Medal.*
1891. Dr. C. J. Forsyth-Major.
1891. Mr. G. W. Lamplugh.
1892. Mr. G. H. Morton. *Medal.*
1892. Dr. J. W. Gregory.
1892. Mr. E. A. Walford.
1893. Mr. E. T. Newton. *Medal.*
1893. Miss C. A. Raisin.
1893. Mr. A. N. Leeds.
1894. Professor John Milne. *Medal.*
1894. Mr. William Hill.

AWARDS OF THE BIGSBY MEDAL,

FOUNDED BY THE LATE

DR. J. J. BIGSBY, F.R.S., F.G.S.

To be awarded biennially "as an acknowledgment of eminent services in any department of Geology, irrespective of the receiver's country; but he must not be older than 45 years at his last birthday, thus probably not too old for further work, and not too young to have done much."

1877. Professor O. C. Marsh.
1879. Professor E. D. Cope.
1881. Dr. Charles Barrois.
1883. Dr. Henry Hicks.
1885. Professor Alphonse Renard.
1887. Professor Charles Lapworth.
1889. Mr. J. J. Harris Teall.
1891. Dr. George M. Dawson.
1893. Professor W. J. Sollas.

AWARDS OF THE PROCEEDS OF THE BARLOW-JAMESON FUND,

ESTABLISHED UNDER THE WILL OF THE LATE

DR. H. C. BARLOW, F.G.S.

"The perpetual interest to be applied every two or three years, as may be approved by the Council, to or for the advancement of Geological Science."

1880. Purchase of microscope.
1881. Purchase of microscope lamps.
1882. Baron C. von Ettingshausen.
1884. Dr. James Croll.
1884. Professor Leo Lesquereux.
1886. Dr. H. J. Johnston-Lavis.
1888. Museum.
1890. Mr. W. Jerome Harrison.
1892. Professor Charles Mayer-Eymar.
1893. Purchase of Scientific Instruments for Capt. F. E. Younghusband.
1894. Mr. Charles Davison.

ESTIMATES *for*

INCOME EXPECTED.

	£	s.	d.	£	s.	d.
Compositions				105	0	0
Due for Arrears of Admission-fees	31	10	0			
Admission-fees, 1894	157	10	0			
				189	0	0
Due for Arrears of Annual Contributions				84	0	0
Annual Contributions, 1894, from Resident Fellows, and Non-residents, 1859 to 1861				1640	0	0
Annual Contributions in advance				85	0	0
Dividends on Consolidated 2¾ per Cents.				100	13	0
Dividends on London and North-Western Railway 4 per cent. Consolidated Preference Stock				87	11	2
Dividends on London and South-Western Railway 4 per cent. Preference Stock				108	19	4
Dividends on London, Brighton, and South Coast Railway 5 per cent. Consolidated Preference Stock				14	12	0
Sale of Quarterly Journal, including Longman's account	165	0	0			
Sale of Geological Map, including Stanford's account	12	0	0			
Sale of Transactions, Library-catalogue, Ormerod's Index, Hochstetter's 'New Zealand,' and List of Fellows	5	0	0			
				182	0	0
				£2546	15	6

THOMAS WILTSHIRE, TREASURER.

January 24th, 1894.

the Year 1894.

EXPENDITURE ESTIMATED.

	£	s.	d.	£	s.	d.
House Expenditure:						
Taxes	5	8	4			
Fire-insurance	15	0	0			
Gas	30	0	0			
Fuel	30	0	0			
Furniture and Repairs	35	0	0			
House-repairs and Maintenance	30	0	0			
Annual Cleaning	15	0	0			
Washing and Sundries	25	0	0			
Tea at Meetings	15	0	0			
				200	8	4
Salaries and Wages, etc.:						
Assistant Secretary	250	0	0			
" Half premium of Life Insurance	10	15	0			
Assistant Librarian and Assistant Clerk	270	0	0			
House Porter and Upper-Housemaid, including Uniform and Allowance for Washing	91	12	0			
Under-Housemaid, including Allowance for Washing	42	12	0			
Errand Boy	26	0	0			
Charwoman and Occasional Assistance	12	0	0			
Accountant's Fee	10	10	0			
				713	9	0
Official Expenditure:						
Stationery	25	0	0			
Miscellaneous Printing	30	0	0			
Postages and other Expenses	90	0	0			
				145	0	0
Library (Books and Binding)				225	0	0
Museum				50	0	0
Publications:						
Geological Map	6	0	0			
Quarterly Journal	900	0	0			
" " Commission, Postage, and Addressing	100	0	0			
List of Fellows	35	0	0			
Abstracts, including Postage	110	0	0			
				1151	0	0
Balance in favour of the Society				61	18	2
				£2546	15	6

N.B.—An expenditure of a sum of £450 has been sanctioned for preparing an Index to the Quarterly Journal. It is unlikely that any of this amount will be expended during the present year, but if required, the balance brought forward from 1893 will be available for the purpose.

Income and Expenditure during the

RECEIPTS.

	£	s.	d.	£	s.	d.
Balance in Bankers' hands, 1 January, 1893 .	311	1	9			
Balance in Clerk's hands, 1 January, 1893 .	16	18	1			
				327	19	10
Compositions				186	18	0
Arrears of Admission-fees	37	16	0			
Admission-fees, 1893	207	18	0			
				245	14	0
Arrears of Annual Contributions				105	13	11
Annual Contributions for 1893, viz.:						
Resident Fellows	1645	17	6			
Non-Resident Fellows ...	14	3	6			
				1660	1	0
Annual Contributions in advance				49	17	6
Dividends on $2\frac{3}{4}$ p. c. Consolidated Stock . .	100	17	3			
,, L. & N. W. Railway Stock . .	87	13	1			
,, L. & S. W. Railway Stock . .	109	1	8			
,, L. B. & S. C. Railway Stock . .	3	13	0			
				301	5	0
Taylor & Francis: Advertisements in Journal, Vol. 48. .					15	4
Publications:						
Sale of Journal, Vols. 1–48	95	10	3			
,, Vol. 49 *	74	4	11			
Journal Subscription in advance		16	4			
Sale of Library Catalogue	1	5	0			
Sale of Geological Map †	15	10	10			
Sale of Ormerod's Index..................	2	2	0			
Sale of Hochstetter's 'New Zealand'		6	0			
Sale of Transactions	3	3	6			
Sale of List of Fellows		6	6			
				193	5	4
Repayment of Income Tax under Schedule C for the year 1892–93				7	8	9
				£3078	18	8

	£	s.	d.
*Due from Messrs. Longmans, in addition to the above, on Journal, Vol. 49, etc.	64	16	0
†Due from Stanford on account of Geological Map...	10	8	7

We have compared this statement with the Books and Accounts presented to us, and find them to agree.

(Signed) HORACE W. MONCKTON, JOHN HOPKINSON, } *Auditors.*

January 27th, 1894.

Year ending December 31*st*, 1893.

EXPENDITURE.

	£	s.	d.	£	s.	d.	£	s.	d.
House Expenditure:									
Taxes				4	4	6			
Fire-insurance				15	0	0			
Gas				24	4	7			
Fuel				22	9	0			
Furniture and Repairs				36	18	7			
House-repairs				11	3	0			
Annual Cleaning				9	11	0			
Washing and Sundries				18	14	1			
Tea at Meetings				14	3	5			
							156	8	2
Salaries and Wages, etc.:									
Assistant Secretary				250	0	0			
,, Half premium of Life Insurance				10	15	0			
Assistant Librarian and Assistant Clerk				270	0	0			
House Porter and Upper-Housemaid, including Uniform and Allowance for Washing				91	11	9			
Under-Housemaid, including Allowance for Washing				42	12	0			
Errand Boy				24	2	0			
Charwoman and Occasional Assistance				6	13	0			
Accountant's Fee				10	10	0			
							706	3	9
Official Expenditure:									
Stationery				18	8	3			
Miscellaneous Printing				31	7	1			
Postages and other Expenses				66	16	11			
							116	12	3
Library							224	19	9
Museum							16	9	3
Publications:									
Geological Map				5	15	10			
Journal, Vols. 1–48				8	4	9			
,, Vol. 49	743	19	8						
,, ,, Commission, Postage, and Addressing	83	4	0						
				827	3	8			
List of Fellows				35	1	2			
Abstracts, including Postage				107	18	11			
							984	4	4
Investment in £150 L. B. & S. C. Railway 5 per cent. Consolidated Pref. Stock, @ 166¾				252	19	0			
Investment in £150 L. B. & S. C. Railway 5 per cent. Consolidated Pref. Stock, @ 164¾				249	16	3			
							502	15	3
Balance in Bankers' hands, 31 Dec. 1893				356	1	2			
Balance in Clerk's hands, 31 Dec. 1893				15	4	9			
							371	5	11
							£3078	18	8

THOMAS WILTSHIRE, *Treasurer.*

'Wollaston Donation Fund.' Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
Balance at Bankers', 1 January, 1893	25	2	9	Cost of striking Gold Medal awarded to Prof. N. S. Maskelyne	10	10	0
Dividends on the Fund invested in $2\frac{3}{4}$ per cent. Consolidated Stock	29	0	0	Award to Mr. J. G. Goodchild	21	18	1
Repayment of one year's Income Tax under Schedule C		14	9	Balance at Bankers', 31 December, 1893	22	9	5
	£54	17	6		£54	17	6

'Murchison Geological Fund.' Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
Balance at Bankers', 1 January, 1893	23	10	10	Award to Rev. O. Fisher, with Medal	21	0	0
*Dividends on the Fund invested in London and North-Western Railway 4 per cent. Debenture Stock	38	19	2	" Mr. G. J. Williams	21	3	10
Repayment of one year's Income Tax under Schedule C	1	0	0	Cost of Medal		17	0
				Balance at Bankers', 31 December, 1893	20	9	2
	£63	10	0		£63	10	0

* This has recently been converted into a 3 per cent. Debenture Stock.

'Lyell Geological Fund.' Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
Balance at Bankers', 1 January, 1893	58	10	6	Award to Mr. E. T. Newton, with Medal	25	0	0
Dividends on the Fund invested in Metropolitan $3\frac{1}{2}$ per cent. Stock	68	9	0	" Miss C. A. Raisin	24	16	3
Repayment of one year's Income Tax under Schedule C	1	15	2	" Mr. A. N. Leeds	24	16	3
				Cost of Medal	1	1	0
				Balance at Bankers', 31 December, 1893	53	1	2
	£128	14	8		£128	14	8

'Barlow-Jameson Fund.' Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
Balance at Bankers', 1 January, 1893	38	10	3	Purchase of Scientific Instruments for Capt. F. E. Younghusband	2	2	0
Dividends on the Fund invested in $2\frac{3}{4}$ per cent. Consolidated Stock	13	7	8	Balance at Bankers', 31 December, 1893	50	2	9
Repayment of one year's Income Tax under Schedule C		6	10				
	£52	4	9		£52	4	9

'Bigsby Fund.' Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
Balance at Bankers', 1 January, 1893	10	8	11	Cost of striking Gold Medal awarded to Prof. W. J. Sollas	11	16	11
Dividends on the Fund invested in 2¾ per cent. Consolidated Stock	5	11	9	Balance at Bankers', 31 December, 1893	4	6	7
Repayment of one year's Income Tax under Schedule C		2	10				
	£16	3	6		£16	3	6

Valuation of the Society's Property; 31st December, 1893.

Property.	£	s.	d.	£	s.	d.		£	s.	d.
Due from Longman & Co., on account of Journal, vol. xlix. etc.				64	16	0	Balance in favour of the Society	11,291	11	6
Due from Stanford, on account of Map				10	8	7				
Balance in Bankers' hands, 31 Dec. 1893				356	1	2				
Balance in Clerk's hands, 31 Dec. 1893				15	4	9				
Funded Property:—	£	s.	d.							
Consolidated 2¾ per Cents. at 97	3769	2	6	3656	1	0				
London & North-Western Railway 4 per cent. Consolidated Pref. Stock at 131.	2250	0	0	2947	10	0				
London & South-Western Railway 4 per cent. Consolidated Stock at 130	2800	0	0	3640	0	0				
London, Brighton, & South Coast Railway 5 per cent. Consolidated Pref. Stock at 162	300	0	0	486	0	0				
Arrears of Admission-fees (considered good)				31	10	0				
Arrears of Annual Contributions (considered good)				84	0	0				
[*N.B.—The above does not include the value of the Collections, Library, Furniture, and stock of unsold Publications.*]				£11,291	11	6		£11,291	11	6

THOMAS WILTSHIRE, *Treasurer.*

January 27th, 1894.

Award of the Wollaston Medal.

In handing the Wollaston Medal (awarded to Geheimrath Professor Karl Alfred von Zittel, For.Memb.G.S.) to Dr. Henry Woodward, F.R.S., for transmission to the recipient, the President addressed him as follows :—

Dr. Woodward,—

The Council of the Geological Society have this year awarded the Wollaston Medal to Geheimrath Dr. Karl Alfred von Zittel, Professor of Geology and Palæontology in the University of Munich, in recognition of the important services which he has rendered to palæontological science during a long period of time. Without alluding in detail to his early work on Austrian geology, much of which was published at Vienna, I wish to point out that, as Oppel's successor at Munich, he has continued to advance our knowledge of the Mesozoic fauna of Central Europe, and more especially of the interesting passage-beds betwixt the Jurassic and the Cretaceous; whilst the memoirs which he has published on these subjects derive additional value from their excellent illustrations.

Twenty years have now elapsed since K. A. von Zittel joined the expedition of Gerhard Rohlfs to the Libyan Desert, and his contributions to the geology of that region are probably the most important that have as yet appeared in relation to Egypt and the adjacent countries. It was on his return from this expedition that he commenced his *magnum opus*, 'The Handbook of Palæontology,' the first part of which was published in 1876 and the last part, relating to the Mammalia, in 1893, thus occupying an interval of 17 years of continuous labour. If proof were needed of the thoroughness of his work, we obtain it in his treatment of the fossil sponges, which he found in so chaotic a state that he applied himself to working out their relations independently, and, having discovered the key in the microscopic structure of their skeletons, was thus enabled to establish a system of classification which has been found equally applicable to recent forms.

It is scarcely necessary to remind you that our Wollaston Medallist has occupied the Chair of Palæontology at Munich for 28 years, during which time he has not only perfected the collections at the museum, but his personal teaching has attracted to his lectures students from almost all parts of the civilized world.

I feel confident, therefore, that the selection of the Council will be cordially endorsed both by the Fellows of our own Society and by all, whether at home or abroad, who are interested in the brilliant record of one of the foremost palæontologists of the age.

Dr. Woodward, in reply, said:—

Mr. President,—

I feel sure that no award of the Wollaston Medal made by the Council of this Society has ever been more popular than that made to Geheimrath K. A. von Zittel, and I only regret that his duties as Dean of the Faculty in his University, and his daily lectures, have prevented him from being present to receive the Medal in person. I shall, however, be happy to convey to him your kind expressions of appreciation for his work; and I beg permission to read to you, from a letter which I have received, the following message addressed to yourself:—

"With respectful thanks I acknowledge the unexpected honour with which the Council of the Geological Society has favoured me, in awarding to me the Wollaston Medal. I need scarcely say how highly I appreciate this distinction, conferred upon me by the most competent of scientific juries. I am really proud to have reached this highest aim for the ambition of every geologist, and I feel particularly pleased to find among the late and present possessors of the Wollaston Medal the name of H. G. Bronn, my first teacher in palæontology, and of Franz von Hauer, who directed my first steps in geological field-work.

"If, through conscientious labour, I have been fortunate enough to contribute somewhat to the promotion of our knowledge of Palæontology and Geology, I feel by your kindly recognition amply rewarded for all the pains that I may have taken in my scientific researches.

"I deeply regret that I am unable to thank you personally, Mr. President; but you may be sure that the honour which you have bestowed upon me will be a strong incentive to make myself more worthy of your confidence by further investigations in the wide field of Palæontology and Geology."

Award of the Wollaston Donation Fund.

The President then presented the Balance of the Proceeds of the Wollaston Donation Fund to Mr. Aubrey Strahan, M.A., F.G.S., addressing him in the following words:—

Mr. Strahan,—

The Council have this year awarded to you the Balance of the Proceeds of the Wollaston Donation Fund, in token of appreciation of your geological work in several parts of England and on the Welsh Border. In solid geology you have especially distinguished yourself amongst the Carboniferous rocks of the Pennine Chain and of North Wales, whilst your contributions to our own Journal, on more than one subject in connexion with the Mesozoic rocks, have evinced the interest that you take in questions arising within your own professional experience. The Glacial Drifts of the Welsh Border and the Glaciation of South Lancashire have also come under your notice in dealing with the difficult subject of Superficial Deposits. Beyond any mere assistance which the Balance of the Fund might render towards further research, the Council, by this Award, desire to express their sense of the value of the work which you have already accomplished.

Mr. Strahan replied as follows:—

Mr. President,—

In thanking you and the Council of the Geological Society for this Award, I wish to express my deep gratification at being honoured by your selection.

During my connexion with the Geological Survey I have, from the nature of the work, been engaged in so many different parts of the country that I have been unable to concentrate my attention on any one formation as closely as might have been the case, and have been led to consider some of the wider problems of geology. I trust, however, that my work has not been without service to those engaged upon the more minute zonal divisions of strata.

In every district in which I have been occupied, geologists with local knowledge have generously placed their observations at my disposal. The only return I could make lay in producing the results of my work as expeditiously and in as useful a form as possible. I take this Award as an indication that I have not been wholly unsuccessful.

Award of the Murchison Medal.

In presenting the Murchison Medal to Mr. William Talbot Aveline, F.G.S., the President addressed him as follows:—

Mr. Aveline,—

The Council have this year awarded to you the Murchison Medal, together with a sum of Ten Guineas, in recognition of the importance of your work as a geological surveyor. Nearly half a century has elapsed since your first communication to this Society, in conjunction with the late Sir Andrew Ramsay, on the structure of portions of Wales. Later on, we find you engaged in mapping and describing some of the Mesozoic Rocks of Central England, and it is now rather more than thirty years since you commenced your work on the Permian and Carboniferous of Nottinghamshire and Derbyshire. Still more recently you were engaged, as district surveyor, on the borders of the Lake Country, being associated with Prof. Hughes, Mr. Tiddeman, and other well-known geologists. That your supervision of the work then progressing has yielded excellent results in relation to the survey of that difficult region is a matter of notoriety.

Although it is some time since you retired from active employment, I feel sure that you will be gratified to find that the record of former years is not overlooked by a generation of geologists, who recognize the value of the work in which you had so large a share.

Mr. Aveline, in reply, said:—

Mr. President,—

It is with feelings of great gratification that I receive this Medal, founded by my former chief, Sir Roderick Murchison, whose friendship and kindness I experienced during the time he was Director-General of the Geological Survey, and in whose company I made some very pleasant geological explorations.

I am very much pleased to think that my work on the Geological Survey has been appreciated by the Council of this Society, and that they should have thought me worthy of receiving this Medal.

Mr. President, I cannot let this opportunity pass without saying a word as to another Director-General of the Geological Survey, the distinguished successor of Sir Roderick Murchison—Sir Andrew

Ramsay, who for over forty years was a sincere friend of mine, and to whom I owe so much for his ready assistance and advice when he was Director of the Geological Survey; we have together worked out many a knotty point in the geology of Wales and elsewhere, tramping together many a mile of mountain and valley. I am sure, if he were living now, he would have rejoiced at the honour this day conferred on me.

I must add that among the most pleasing results of receiving this Medal are the kind congratulations which I have received from my former colleagues.

Award of the Murchison Geological Fund.

The President then handed the Balance of the Proceeds of the Murchison Geological Fund to Mr. George Barrow, F.G.S., addressing him as follows:—

Mr. Barrow,—

The Balance of the Proceeds of the Murchison Geological Fund has been awarded to you by the Council as a testimony of the value of your geological work both in Yorkshire and in Scotland. As regards the former district, I would draw especial attention to your description of the geology of North Cleveland. Since your transfer to the Survey of the South-east Highlands you have evinced a remarkable aptitude for petrological studies, whilst your recent paper in the 'Quarterly Journal' on the Muscovite-biotite Gneiss of Glen Clova bids fair to rank high in that category. The Council hope that this mark of appreciation may not only aid but encourage you to further research in the same direction.

Mr. Barrow replied in the following words:—

Mr. President,—

I beg to thank the Council for the unexpected honour that they have done me in conferring this Award. In receiving it at your hands, Sir, pleasant memories are revived of my early geological days in East Yorkshire, when your writings were of much assistance to me. In those happy times we had no difficulty in deciding which way up the succession lay. But now, in working on the

Highland Series, it is often difficult, if not impossible, to decide this very elementary point, and any kindly encouragement in such work is most welcome. It is the more welcome as in this case it is a recognition that my efforts so far are not entirely without value.

Award of the Lyell Medal.

In handing the Lyell Medal (awarded to Prof. John Milne, F.R.S.) to Prof. J. W. Judd, F.R.S., V.P.G.S., for transmission to the recipient, the President addressed him as follows:—

Professor Judd,—

The Lyell Medal, with the sum of Forty-six Pounds, has been awarded to Prof. John Milne, F.R.S., of the Imperial College of Engineering, Tokio, Japan, in testimony of appreciation of his investigations in Seismology. It must ever be regarded as a fortunate event, in the interests of science, when Prof. Milne went to reside in Japan. Undoubtedly his opportunities in that oscillating region have been great, but he has been fully equal to the occasion, and may with justice be regarded as the founder of seismic science in that country. His efforts in this direction are in part recorded in the annual volumes of the Seismological Society of Japan, to which he has always been one of the most important contributors. Stimulated no doubt by this good example, the Government of Japan has taken up the study of earthquakes by establishing some 700 stations for observations, so that, to use Prof. Milne's own words, "phenomena, which were formerly matters of hypothesis, are now no longer unexplained."

It is indeed the eminently practical turn given by Prof. Milne to the study of earthquakes which commends his work so effectually to geologists, and ever since his seismic experiments, in conjunction with Mr. Gray, and the reports published by the British Association on the investigation of the Earthquake Phenomena of Japan, Prof. Milne has been recognized as one of the leading authorities in this branch of science. Bearing in view, also, the delicate and costly nature of seismological apparatus, the Council feel justified in awarding a considerable sum of money, out of the Fund, to accompany this Medal.

Prof. Judd, in reply, said:—

Mr. President,—

Although I rise at short notice, it is with extreme satisfaction that I receive at your hands this Award to Prof. Milne. It was my good fortune to be acquainted with the recipient of this Medal and Fund before he left this country for Japan; and during his long residence in that distant land I have had the privilege of frequent correspondence with him. The cheerful courage with which he has faced unpromising surroundings, the resourceful tact with which he has met every difficulty, and the unconquerable energy with which he has surmounted the greatest obstacles, are known to all of us. You, Sir, have referred to the admirable work done by the Seismological Society of Japan, and it is not too much to say that during a long period Prof. Milne might have justly asserted "I am the Seismological Society." The foundation of that Society and the Seismological Magazine was due to the wise foresight and the unflagging energy of Prof. Milne himself, and to the efforts of the pupils whom he has instructed, and whose enthusiasm he has fired. I feel assured that the Fund which you have asked me to place in his hands will be administered in the best interests of Geological Science. It was my good fortune to know, very intimately, the founder of this Medal and Fund, and I am persuaded that the Council of this Society never more truly fulfilled his wishes and never more fully conformed to the terms of his bequest—both in their letter and spirit—than when they decided to make this Award to Prof. John Milne.

Award of the Lyell Geological Fund.

The President then presented the Balance of the Proceeds of the Lyell Geological Fund to Mr. William Hill, F.G.S., and addressed him in the following words:—

Mr. William Hill,—

The Balance of the Proceeds of the Lyell Geological Fund has been awarded to you in testimony of the value of your work amongst the Cretaceous rocks of this country during the last eight years. In collaboration with Mr. Jukes-Browne, you have made

communications to this Society on the Upper Cretaceous strata of East Anglia, which are recognized as being of the highest importance. Similar investigations, moreover, were prosecuted by yourself alone with equal success in Lincolnshire and Yorkshire. Your intimate acquaintance with the lithological characters of the various members of the series has materially aided your stratigraphical and palæontological knowledge in arriving at correct results. It is hoped that this acknowledgment of your services to Geological Science may encourage you to continue your researches.

Mr. Hill replied as follows:—

Mr. President,—

I desire to convey my heartiest thanks to the Council of this Society for the Award which you have just placed in my hands. My geological work has been undertaken chiefly to fill my spare time, and I feel my reward ample in the pleasure which geological study has given me, and in the kindly reception of my papers at the hands of this Society. The unexpected honour you confer is to me more gratifying than I can well express.

You have spoken of the value of my work, but I must not forget that this is much enhanced by the help which I have received from many Fellows of the Society, and especially from one who is not often with us. I take this opportunity of thanking them most heartily. I need hardly say, Sir, that the Award will stimulate me to further efforts in the cause of Geological Science.

Award of the Barlow-Jameson Fund.

In handing a portion of the Proceeds of the Barlow-Jameson Fund to Mr. Charles Davison, M.A., the President addressed him as follows:—

Mr. Davison,—

A sum of Twenty-five Pounds from the Proceeds of the Barlow-Jameson Fund has been awarded to you in token of appreciation of your work in geological dynamics—including under that term the study of earthquakes. In this connexion I would more especially

allude to your valuable notice of the Inverness earthquakes of 1890, wherein your conclusions with reference to the Great Glen of Scotland open out views of the utmost importance in relation to the Highland faults. We are also indebted to you for calculations on the movement of scree-material, based on the expansion of the stones through heat.

Geologists, I may say, are always glad to receive assistance from mathematicians, and it is to be hoped that this acknowledgment on the part of the Council of the value of your work may have the effect of stimulating you to further study in that direction.

Mr. Davison, in reply, said:—

Mr. President,—

If anything could add to the welcome and gratifying character of this Award, it would be the words of kindness and encouragement that have accompanied it. For both I beg to tender my sincere and hearty thanks. I have been told, Sir, and in my own case I feel sure it must be so, that the Council in awarding these Funds look not so much to the past as to the future. I wish I could do more than assure the Council that my best efforts will be used to prevent their kindly hopes from being disappointed.

THE ANNIVERSARY ADDRESS OF THE PRESIDENT,

W. H. Hudleston, Esq., M.A., F.R.S., F.L.S.

Gentlemen,—

Our losses through death have again been very considerable, and although few of those whom we deplore were at any time actively engaged in the work of the Society, yet the number of Fellows, deceased since the last Anniversary, who had achieved distinction in other branches of science must be regarded as noteworthy.

John Tyndall, F.R.S., Honorary Professor of Natural Philosophy at the Royal Institution, was born near Carlow on the 21st August, 1820, being descended from an old English family of that name, a branch of which had migrated to Ireland in the days of the Stuarts. At 19 years of age he joined the Ordnance Survey under Col. Owen Wynne, and was afterwards employed as a surveyor during the press of railway construction in England. In 1847, when the railway mania had somewhat abated, he accepted an educational post at Queenswood College in Hampshire. The following year, in company with Dr. Frankland, Mr. Tyndall went to the University of Marburg, where he enjoyed the advantage of the instruction and co-operation of such men as Bunsen and Knoblauch. About 1853 he joined the staff at the Royal Institution, having been elected a Fellow of the Royal Society a year previously. His career at the Royal Institution is too well known to need repetition here. It is enough to indicate that, on the proposal of Faraday, Tyndall was appointed Professor of Physics, and he held the post until 1887, having been throughout that long interval one of the most popular and effective of lecturers.

On his retirement from this chair a complimentary dinner was given to Prof. Tyndall, which was attended by a large number of distinguished men. Since that date he withdrew to a very great extent from public scientific work, having retired to his chosen abode on Hind Head, where, but for the encroachments of his neighbours, he was content to pass a quiet time. Here it was, that owing to the results of an unfortunate mistake, he died on the 4th December, 1893, in the 74th year of his age. On the 15th of the same month a special general meeting of the Members of the Royal Institution was held for the purpose of passing a vote of sympathy

and condolence with Mrs. Tyndall on the occasion of her husband's death.

It is not for us to consider the work of Tyndall as a physicist, though it will be readily conceded that his powers as a scientific expositor have hardly ever been equalled. Although he joined this Society in 1868, it cannot be said that he ever took any active part in the study of geology, nor has he ever contributed a paper to our publications. But there have been certain problems more or less connected with geological science to which he turned his ever active mind, and to which brief allusion may be made, though these relate to work achieved long ago. A notice of Tyndall's ideas on the subject of slaty cleavage may be found in the introduction to his famous work, 'The Glaciers of the Alps,' first published in 1860. Well-nigh forty years have elapsed since that memorable visit to the Penrhyn Slate Quarries, where his interest was aroused by what he saw of the phenomena of slaty cleavage. He tells us he there found, on enquiry, that the subject had already attracted the attention of three English writers, Prof. Sedgwick, Mr. Daniel Sharpe, and Mr. Sorby. Through Sedgwick he learned that cleavage and stratification were things totally distinct from each other, but he was obliged to disagree with his learned preceptor on the point that slaty cleavage is of the same nature as crystalline cleavage. Tyndall was not long in giving his adhesion to the mechanical theory, and he justly remarked that science was indebted to Sharpe and Sorby for the prime facts on which that theory rests. In another department Tyndall's glacier work has been of great service to geologists for the last five and thirty years, though not in itself devoted, to any considerable extent, to the solution of geological problems. He is credited with a belief that glaciers were possessed of considerable excavating power, contrary to doctrines which have of late prevailed. Nevertheless the whirligig of time brings old fashions back again, and thus it comes to pass that the lake-basin theory has lately had some able advocates. Tyndall also took an interest in the subject of the Parallel Roads of Glen Roy, and was a supporter of Jamieson's glacier-dam theory, though he never took any trouble to ventilate these opinions in the geological literature of the day.

The Rev. CHARLES PRITCHARD, F.R.S., Professor of Astronomy in the University of Oxford, was born about the year 1810. He graduated at St. John's College, Cambridge, where he took his degree as fourth wrangler, being also a Fellow of his College. For many

years he was head master of the Clapham Grammar School, and in 1870 was elected to the Savilian Chair at Oxford. His contributions to astronomical science are well known, and in 1886 he was awarded the gold medal of the Royal Astronomical Society for his *Uranometria Nova Oxoniensis.* He became a Fellow of this Society in 1852, but does not appear to have contributed papers or taken any active part in its work. Dr. Pritchard died at his house in Oxford on the 28th May, 1893, in his 84th year.

Thomas Hawksley, F.R.S., M.Inst.C.E., was born in 1807 at Nottingham, for which town he was appointed to construct water-works about the year 1830. Subsequently he became so famous in this line of business that he is said to have constructed above one hundred and fifty, many of them large undertakings. To his ingenuity we owe the system of 'constant service' water-supply. He also rendered great help to Sir Joseph Bazalgette in connexion with the main drainage of London, and gave on more than one occasion important evidence with reference to the water-supply of the metropolis. Mr. Hawksley was elected a Fellow of this Society in 1870, though he never contributed a paper or took any active part in our Proceedings. Yet it may well be supposed that he frequently encountered questions essentially geological, when deciding on the sites of storage-reservoirs, and especially in determining how deep to carry the puddle-walls below the valley-bottom. In such cases he usually availed himself of the advice of skilled geologists, and, as a result of the sinking of trial-shafts, was sometimes able to detect slight errors in the published maps, which he was always ready to notify to the proper quarter.

Mr. Hawksley, who was President of the Institute of Civil Engineers in 1872–1873, must ever be regarded as one of the most eminent engineers of this country. He died in London on the 23rd September, 1893, at the age of 86.

Edward Bouverie Luxmoore, M.A., was born about 1829 at Marchwiel, in Denbighshire, and was educated at Eton and Trinity College, Cambridge. For many years he resided at Bryn Asaph, near St. Asaph, and was a Justice of the Peace for Flintshire.

Although Mr. Luxmoore does not appear to have written anything on geology himself, he took a great interest in the science. His hospitable mansion was well known to geologists visiting the neighbourhood, and he was well informed on the geology of

Denbighshire and Flintshire. In 1883–84 Mr. Luxmoore began on his own account the exploration of the Caves at Ffynnon Beuno and Cae Gwyn, and during the exhaustive work carried on under grants from the Royal Society and the British Association, from 1885–87, he rendered great assistance, and was one of the committee. In 1887 he was elected a Fellow of this Society. He died very suddenly at Locarno, in Italy, on March 27th, 1893, at the age of 63.

Charles Edward Austin, Assoc.M.Inst.C.E., was born at Wotton-under-Edge on the 22nd June, 1819. As a young man he was engaged under Brunel in the construction of the Great Western Railway, which was opened through to Bristol in 1841. Afterwards he resided in Russia, devoting his attention to the steam-navigation of the Volga. He was elected a Fellow of this Society in 1858, and four years later communicated some notes 'On a locality in Siberia where Fossil Fish and *Estheriæ* have been found.' For many years he was engaged in the construction of foreign railways, especially in Eastern Europe and Asia Minor. In the latter country, about ten years ago, he worked a mining concession at a considerable loss of time and money. He was also engaged in enterprises for dealing with the sewage of towns, and published treatises on the subject.

Mr. Austin died on the 8th April, 1893, aged 74 years.

Sir James Anderson was born at Dumfries in the year 1824. Having received his early education in his native town, he entered the mercantile marine at the age of 16, and ultimately rose to the command of one of the Cunard line of steamships. His chief scientific work was in connexion with the laying of the Atlantic cable, when he was in command of the 'Great Eastern.' In November 1866 he received the honour of knighthood on the successful completion of that undertaking. About four years afterwards he joined this Society, though I am not aware that he ever took any active part in its work. Sir James Anderson died in London on the 7th May, 1893, in his 69th year.

James William Davis, F.L.S., F.S.A., was born in the neighbourhood of Leeds on the 15th April, 1846, and received his early education at the grammar school of that town. When about 18 years old he accompanied his father's family to Halifax, where he

was one of the successful students at the Haley Hill College, having taken the Society of Arts' silver medal for chemistry. This kind of training was eminently suitable for the dyeing business, in which his family was engaged; but these matters did not absorb the whole of young Davis's attention. When quite a schoolboy he began collecting objects of natural history, and at a very early age was elected secretary of the Leeds Naturalists' Society. And thus it was that, throughout the whole of his most active life, business and science were always combined, and he generally managed to do ample justice to both.

Mr. Davis was about 27 years of age when, after having devoted some time to archæological and antiquarian pursuits, he joined this Society in 1873. He had now become a confirmed geologist and palæontologist, and during the twenty years that he was a Fellow of the Geological Society contributed at least nine papers to its 'Proceedings,'—the first, in 1876, having been on a "Bone-bed in the Lower Coal-measures, with an Enumeration of the Fish-remains of which it is principally composed." His contributions to our own publications, in fact, related chiefly to fishes of Carboniferous age, which he had made his especial study.

Among his contributions on fossil ichthyology to various other scientific societies may be mentioned the monographs published by the Royal Dublin Society—'On the Fossil Fishes of the Mountain Limestone of Great Britain' (1883); 'On the Fossil Fishes of the Chalk of Mount Lebanon and Syria' (1887); and 'On the Fossil Fishes of the Tertiary and Cretaceo-Tertiary Formations of New Zealand' (1888). In order to bring out such works as these their Author, besides drawing on the resources of his own splendid collection and on those of the museums of this country, was in the habit of travelling extensively abroad, visiting museums, it may be said, almost all over Europe. Of his energy and enthusiasm in the cause there can be no doubt whatever, but if palæontology is year by year getting more into the hands of the trained specialist, this is emphatically the case with such obscure and difficult subjects as are presented by the fossil vertebrata of the older formations.

We must now consider Davis as a geologist, more especially in connexion with his native county. It was owing to his exertions that the Yorkshire Geological and Polytechnic Society became an important and useful body. Some twenty years ago that Society was on the verge of dissolution. The advent of Mr. Davis to the secretaryship changed this state of affairs, and, by dint of enthusiasm

and perseverance, he raised it to a prosperous and useful condition, whilst the number of its members was nearly quadrupled. At the jubilee meeting of the Society, held in Ripon in 1888, the opportunity was seized to present Mr. Davis with some mark of the esteem in which he was personally held by the members, and also in part recognition of his great services as honorary secretary and editor of the 'Proceedings.' It is scarcely necessary to add that Mr. Davis himself was a large contributor to those 'Proceedings'; and in 1889 he wrote the history of the Society, constituting the bulk of the tenth volume. He was also an active member of the Yorkshire Naturalists' Union, nor must his work on the Geology of West Yorkshire, in conjunction with Mr. Lees, be forgotten.

Mr. Davis became a member of the British Association in 1873, and was a permanent member of their General Committee. His communication on the Exploration of a Fissure in the Mountain Limestone of Raygill was published in the Report for 1881, a fuller account being given in the Proceedings of his own Society. It was about this time that I had the pleasure of making Mr. Davis's acquaintance, which speedily led to our undertaking the joint directorship of the midsummer excursion of the Geologists' Association of London to the West Riding, where the Raygill fissure was to be one of the objects of investigation. This was in 1882, when I first learnt to appreciate Mr. Davis's methods and his knowledge of the geology of the Craven district. At that time he was especially interested in the group of erratics near Norber.

That Mr. Davis was not idle as a scientific writer may be inferred from the fact that a list of 56 memoirs and papers of his is given in the last volume of the 'Geological Magazine' (1893), several of them having appeared originally in its numbers. But this is only one side of the picture; for Mr. Davis had a civic career such as few subjects of Her Majesty ever attain to. For many years he was distinguished as a public man, and especially as an advocate of technical education; and not content with promoting Mechanics' Institutes and Halls, he even commenced an agitation to form a Yorkshire Fine Art Society, of which for some years he was secretary. His house at Chevinedge, near Halifax, is said to have been rich in the treasures both of science and art, and he had also got together a considerable library. Anything rare or novel he was ready to lend to the Halifax Museum or other local exhibitions; and it is almost unnecessary to say that he took great interest in the Scientific Society of that town, of which society he was at one time President.

Not to dwell too long upon his career as a citizen, it may be sufficient to say that Mr. Davis was installed Mayor of Halifax in November 1890, and it was in the following February that he entered the Council of the Geological Society, serving on it for two years. So pleased were his fellow-townsmen with their Mayor that they elected him three times in succession to fill that office, and well might it have been for him if his friends had been less exacting: for the Nemesis which attends over-exertion had already cast a shadow upon him, as nearly two years have now elapsed since he first began to suffer from insomnia. Change of scene, so far as his engagements would allow, was tried on different occasions with partial success, and few would have conjectured when Mr. Davis was with us at our last Anniversary Meeting that his end was so near. Later in the spring he went on a visit to Paris, and, not benefiting much by the change, tried some rural districts in Yorkshire, finally settling at his old quarters in Bridlington, where he died very suddenly on July 21st, 1893, at the early age of 47.

George William Shrubsole was born at Faversham, in Kent, in 1827, and when a young man made his way to Chester, where he resided for the past forty years in business as a chemist. He was well known to his fellow-citizens in connexion with the Chester Society of Natural Science, of which, along with the late Canon Kingsley, he was one of the founders. He was appointed first Chairman of the Geological Section of that society, a post he held for twenty years, and was, moreover, their first Honorary Curator. During this period he arranged and largely added to their collection of Lower Silurian fossils from the Glyn Ceiriog district, in addition to other work. He was also well known for the interest he took in archæological research.

Mr. Shrubsole became a Fellow of this Society in 1873, and has been in correspondence with the officers on more than one occasion, notably when he succeeded in recovering some specimens of fossil fishes belonging to our museum from the waters of the Dee. In biology and palæontology he has principally worked among the mollusca and some of the lower invertebrates.

Mr. G. W. Shrubsole was one of three brothers, all of whom have made communications to this Society in their capacity as Fellows. He died at Chester on July 21st, 1893, at the age of 66.

Edward Charlesworth was born at Clapham, in Surrey, on the 13th September, 1813, being the eldest son of the Rev. John Charlesworth, rector of St. Mildred, Bread Street, London. Much

of young Edward's early life was spent in Suffolk, where his father was at that time rector of Flowton, near Ipswich, and he enjoyed exceptional advantages in being able to visit the numerous Crag pits and other excavations in that neighbourhood. On these occasions the father encouraged his children to observe and collect fossils, and thus they all more or less imbibed a love of geology, which became especially strong in the eldest.

Charlesworth was educated at the private school of the Rev. W. Kinchin, afterwards rector of St. Stephen's, Ipswich; and the medical profession having been chosen for his career, he was articled to an eminent London physician and became a pupil attached to Guy's Hospital. But his love of geology was stronger than his liking for medicine, and the study of fossil bones had more attractions for him than that of mere human anatomy. And thus it came to pass that after his articles had expired he turned to geology, and especially to palæontology, with all his heart.

In 1835 he joined this Society, being then 22 years of age, and about the same time gave proof of his excellent knowledge of the East Anglian Crag in a paper published in the 'Philosophical Magazine,' wherein the divisions now established were for the first time clearly indicated. It was at this period likewise that he became connected with the Zoological Society and the British Museum, where he held responsible posts, besides being the proprietor and editor of Loudon's 'Magazine of Natural History.' He was also appointed Honorary Curator of the Ipswich Museum, where some of his early collections of Crag fossils are still preserved. But all these engagements were unfortunately relinquished on his accepting an offer to go out to Central America in 1840, under circumstances which promised to be of great interest and importance in opening to him a wide sphere for studying the geology of that region. The indisposition of his fellow-traveller shortened that tour to a few months' duration, and Mr. Charlesworth returned to resume his researches in England.

His intimate acquaintance with the Crag now enabled him to assume the position of chief authority in matters connected with that formation, and his love of fossils, added to his undoubted biological and palæontological knowledge, caused him to extend his interest to the splendid shells of the older Tertiaries in Hampshire and the Isle of Wight. Probably no one rivalled him in arranging and classifying geological collections in museums—a work he was often called upon to undertake in addition to his literary labours.

Mr. Charlesworth in those days was never idle, though his somewhat contentious disposition, as evinced at the British Association and elsewhere, not seldom involved him in disputes. When in this mood he was quite as ready to attack men such as Owen and Lyell as to fly at smaller game. Although at one time a prolific writer, his communications to this Society were not numerous; yet it is worthy of record that he contributed a note on the genus *Physeter* (or sperm-whale) in the Red Crag of Felixstowe to the first volume of the Quarterly Journal, just half a century ago.

In the same year, viz. in 1844, Mr. Charlesworth was appointed successor to Prof. John Phillips as curator to the museum of the Yorkshire Philosophical Society at York. There he continued to reside for 14 years, during which time he obtained a considerable insight into the Jurassic and Carboniferous fossils for which Yorkshire is so famous. He also spread throughout the county an interest in collecting, and was instrumental in keeping alive a taste for geology. But, as his opinions on certain points were too advanced for the more orthodox inhabitants of the ancient city, he found it advisable to give up his post in 1858, returning once more to London.

As a man of science, in the stricter acceptation of the term, Charlesworth's career may be almost said to have terminated when he threw up this appointment 36 years ago. He was still able to utilize his unique knowledge of Crag and other Tertiary fossils, and to this he added a curious interest in flints and their history; but on the whole his views may be said to have crystallized early, and he took but little part in modern geological development. From this time forth his energies were principally devoted to the buying and selling of fossils. Not that he was a dealer in the ordinary sense of the term, for he thoroughly understood the palæontological history of his wares, and could arrange and name a collection better perhaps than any man. Not unmindful of his former connexion with the British Museum, he was ever anxious to supply that establishment with the choicest things. But he generally had some exquisite specimen, temptingly displayed on pink cotton wool in a glass-topped box, for his private customers, of whom Mr. Reed, of York, must always be deemed the chief.

The last 20 years of his life were greatly clouded by long and severe illness, frequently confining him to his bed-room, and almost entirely preventing him from doing anything in the way of searching for fossils. During this interval he occasionally appeared at the

meetings of Societies, where his original fluency as a speaker never deserted him, and where he would propound geological puzzles, or descant on the origin of flint, as was lately the case at the Victoria Institute. Quite recently, indeed, he was in the habit of attending the meetings of that Society and participating in their discussions. By this time he had retired to Saffron Walden, only occasionally coming to London; and when a prisoner through illness, his boxes of fossils and his pamphlets and manuscripts of all descriptions used to be heaped around his bed, almost filling up the room. A friend estimated that there was a ton and a half of flint fossils in that apartment at the time of his death. This event occurred at Saffron Walden on the 28th July, 1893, when Mr. Charlesworth only wanted a few weeks of completing his 80th year.

The Rev. LEONARD BLOMEFIELD (originally JENYNS) was born in London on the 25th May, 1800, being the son of the Rev. George Leonard Jenyns, of Bottisham Hall, near Cambridge. He received his education at Putney, at Eton, and at St. John's College, Cambridge, graduating in 1822. Young Jenyns was at all times an ardent naturalist, and used, when a boy, to have rare birds sent to him in London from the family estate at Bottisham. He was Charles Darwin's senior by ten years when they hunted butterflies together in the adjacent fen, and his early collections are in the museum of the Cambridge Philosophical Society. He held the living of Swaffham Bulbeck, in the same county, for at least thirty years.

Mr. Blomefield was elected a Fellow of the Linnean Society in 1822, and for many years distinguished himself in botany and zoology. The 'Fishes of the Voyage of the 'Beagle,'' written at the express request of his friend Darwin, was one of the works which gave him the most satisfaction. He was also interested in meteorology, and one of the founders of the Entomological Society. There is no record of his having paid any special attention to geology, but he was elected a Fellow of this Society in December 1835, the certificate being signed by A. Sedgwick, J. S. Henslow, R. Murchison, and W. Clift. He wrote a memoir of Prof. Henslow some years afterwards. In 1871 the surname and property of Francis Blomefield, the celebrated historian of Norfolk, devolved upon Mr. Jenyns, who made Bath his residence during the later years of his life. He was the founder and first President of the Bath Natural History and Antiquarian Field Club, and the donor of the Jenyns Library, a gift including his Herbarium of British Plants,

the result of his life-work as a botanical collector. At the time of his death Mr. Blomefield was the father of the Linnean Society, having been a Fellow for over 70 years, and for nearly 59 years a Fellow of this Society. He died at Bath on September 1st, 1893, in his 94th year.

Harry Macdonald Becher, A.R.S.M., was born at Simla in 1855, and educated at private schools in England until he reached the age of 13, when he was sent to Dresden. His education as a mining engineer was commenced at Freiberg and completed at the Royal School of Mines in Jermyn Street, where he became an Associate in 1875, and was the same year elected a Fellow of this Society. Originally engaged by the Borneo Company, Mr. Becher spent many years in the Malay Peninsula and other parts of the far East, during which he visited China and Japan and even Siberia, reporting on coal-deposits in those regions. In 1883 he returned to China for the purpose of investigating the mineral resources of Korea, and subsequently established the first Chinese gold-mine and quartz-mill in Chantung. The Christmas of 1887 found him in the jungles of North-eastern Siam reporting on gold-mines there, and in the following year he was engaged at the Pahang gold-mines, near Singapore.

Mr. Becher several years ago contributed a note on some cupriferous shales in the province of Hon-peh, China, to the Quarterly Journal, and about a year ago he gave us a short paper on the gold-quartz deposits of Pahang. He also read a paper on 'Mining in the Malay Peninsula' before the Institution of Mining and Metallurgy when he was last in England.

Shortly after his return to the East Mr. Becher was unfortunately drowned in fording one of the Malayan rivers, the news being received in England with the most profound regret by a large circle of attached friends. This event took place on the 16th September, 1893, when he was only 38 years of age.

John Spencer was born in the year 1821. He was by profession a mining engineer, and about 25 years ago became a Fellow of this Society. There is a short note of his in the Quarterly Journal on Boulders found in Coal-seams, and on the evidence of Ice-action in Carboniferous times. He resided at Manchester, and died there on September 20th, 1893, at the age of 72.

The Rev. H. W. CROSSKEY, LL.D., was born at Lewes, in Sussex, on the 7th December, 1826. After some experience as a minister in the Midlands, he accepted in 1852 the charge of an Unitarian congregation at Glasgow, where he remained for 17 years. During the whole of that period he evinced much interest in scientific matters, being actively connected with the Philosophical and Geological Societies of that city. Subsequently he returned to Birmingham, where he resided for the last 24 years, always evincing an interest in science and education. He was well known as an authority on Glacial Geology, and the author of a valuable series of Reports on the Erratic Blocks of this country, communicated during the past 20 years to the British Association. He became a Fellow of this Society in 1868, and occasionally contributed papers on post-Tertiary fossils. He also co-operated with Robertson and Brady in describing the post-Tertiary Entomostraca in the Palæontographical Society's volume for 1874.

Dr. Crosskey died at Edgbaston, near Birmingham, on the 1st October, 1893, having nearly completed his 67th year.

JOHN BAILEY DENTON, M.Inst.C.E., was born in November 1814. In early manhood he was associated with Brassey and Locke in the construction of the Great Northern and many other railways. More than half a century ago he acquired celebrity by the enquiry—still a very pertinent one—'What can be done for British agriculture?' His fame as a drainer of soils is well known, and it was, in all probability, the interest that he took in this branch of practical science which induced him to join the Geological Society. This step was taken in 1854, but Mr. Denton never made any contribution to our Proceedings, nor participated in any way, so far as I know, in the active work of the Society. Still there can be little doubt that our publications were useful to an engineer who devoted his attention for so many years to the storage of water, and the methods of purifying sewage by means of percolation through soil. Mr. Denton had been a Hertfordshire magistrate for upwards of a quarter of a century, and died at Stevenage, in that county, on November 19th, 1893, in the 79th year of his age.

JOHN PLANT, Major of Volunteers, was born in Leicester about 1820. Early in life he evinced a love of natural history, and assisted in forming the local museum in his native town. In 1849 he was selected by the Corporation of Salford as their librarian and curator of the borough museum, duties which he discharged with great

satisfaction to all for over 40 years. During this period he paid considerable attention to geology, and wrote several papers, chiefly for the Manchester Geological Society. He died early in January 1894, at the age of 74, and was buried at Rhosneigr, on the coast of Anglesey.

Count ALEXANDER VON KEYSERLING, Foreign Member of the Geological Society, was born on the 15th August, 1815, at Kabellen, in Courland. In early life he studied at the University of Berlin under Humboldt, Von Buch, and other distinguished men of that period. It was for this reason that, in 1841, he was selected along with Lieut. Kokscharow to accompany Murchison and De Verneuil on their second tour in Russia, when geological observations were made in the governments of Wilna, Courland, Livonia, and Esthonia. He also remained with Murchison's party during the special geological survey which was made by order of the Emperor Nicholas, and the results of which were given to the world in 'The Geology of Russia and the Ural Mountains,' published in 1845.

In the year 1842 Von Keyserling visited England and France for the purpose of comparing the rocks of these countries, in the field, with the rocks of Russia, and also to collect specimens for the Institute of Mines at St. Petersburg. With this object he and Murchison started from London and practically made the tour of Great Britain in their endeavour to gather materials for the illustration of their Russian work; visiting amongst other places the county of Durham, in order to compare the rocks and fossils of that region with those of the Russian province of Perm. It was in this year also, when Murchison was President of the Society, that a joint paper by himself, De Verneuil, and Von Keyserling, 'On the Geological Structure of the Central and Southern Regions of Russia and the Ural Mountains,' occupied three successive meetings in its delivery.

In 1844 Von Keyserling was again with Murchison, who had been charged to convey to the Emperor Nicholas a gold medal struck in honour of his visit to the Queen of England. Further information was then given by him to Sir Roderick for their great work on the geology of Russia and the maps illustrating it. The subsequent career of Von Keyserling is less directly connected with that of English geologists; but we find that he continued to be honoured in his own country, where he was for some time connected with the Imperial Corps of Mines, and, in 1859, was appointed Assistant State Geologist. Between 1862 and 1869 he was Dean of the University of Dorpat, returning in the latter year to Rayküll, in

Esthonia, where he spent the remainder of his life, much respected by all. On December 27th, 1887, the Geological Committee of the Institute of Mines at St. Petersburg, with many other societies and friends, celebrated the jubilee of his scientific work. On this occasion a congratulatory letter was sent to him from the Council of this Society.

Von Keyserling died at Rayküll on the 8th May, 1891, in the 76th year of his age. For some reason this obituary notice has been delayed.

Prof. Juan Vilanova y Piera, Foreign Correspondent, was born at Valencia in 1822. He was originally brought up to the medical profession, obtaining his degree of licenciate in 1845, but hardly ever practised, as in early life he devoted himself to geological pursuits. About the year 1853 the Spanish Government gave him a commission to study geology in different European countries, and he travelled accordingly for a considerable number of years. On his return to Spain he was promoted to the Chair of Geology in the Natural History Museum at Madrid, a post which he held till 1873, when he became the first occupant of the new Chair of Palæontology. About this period he also brought out a text-book of geology, for a long time the only one in the Spanish language.

As a member of the national Survey he studied the geology of the provinces of Teruel, Castellon, and Valencia, and published geological maps and memoirs relating to them. Of late years he was much interested in prehistoric subjects, and besides his publications he endeavoured to popularize this branch of study by frequent lectures in Madrid and the provinces. Agriculture also, in its relations to geological science, was one of his favourite themes.

Vilanova died at Madrid on the 7th June, 1893, having just completed his 71st year.

Karl August Lossen, Foreign Correspondent, Professor of Petrography and Geology in the University and Mining Academy, Berlin, was born on the 5th January, 1841, at Kreuznach, in Rhenish Prussia, where his father was in the medical profession. After leaving school young Lossen chose mining—a career which he afterwards gave up in order to turn his attention to geology and more especially petrography. In 1869, he took his degree in the philosophical faculty of the University of Halle with his thesis '*De Tauni montis parte transrhenanâ*,' having also obtained much geological experience under Beyrich in the Harz. In 1872, on his admission to the Prussian Geological Survey, he was commissioned by the

Directors with the investigation of that district, and the admirable map of the Harz, subsequently published by the Survey, was mainly his work.

Lossen's researches in the Harz caused a new departure in petrography, and he is regarded as the founder of 'dynamo-metamorphism,' which treats of the effects of mechanical force on the structure of rocks. He supplied evidence of differentiation in rock-magmas, being particular in the determination of rocks according to their structural and chemical characters with reference to their mode of occurrence, whilst he studied the various results of the consolidation of one and the same magma under various conditions. He was not a voluminous writer, but his communications were careful and elaborate. Most of his publications are to be found in the 'Jahrbuch der königl. Preussischen geologischen Landesanstalt und Bergakademie,' in the volumes of the German Geological Society, and in the Proceedings of the 'Gesellschaft der naturforschenden Freunde.' Though terribly afflicted with deafness, which precluded him from general conversation, Prof. Lossen was well able, through his exceptional command of language, to carry all before him when a suitable occasion arose.

He died at Berlin, after a long and painful illness, on the 24th February, 1893, at the age of 52.

Dionys Stur, Foreign Member, was born on April 5th, 1827, at Beczkó, in Upper Hungary, at which place his father was schoolmaster. After completing his classical studies at the Gymnasium (=Grammar School) at Modern, and his course of philosophy at the Protestant College at Pressburg, Stur attended the mathematical and physical classes at the Vienna Polytechnikum, and subsequently the public lectures on mineralogy and geognosy, which were delivered in the later 'forties at the Imperial-Royal Museum of Mines by Herren von Haidinger, von Hauer, etc. He perfected his professional training at the Imperial-Royal Mining Academy in Schemnitz.

Thoroughly prepared in this wise for the calling of a field-geologist, and well endowed in body as in mind, Stur joined, in April 1850, the then newly-established Imperial-Royal Geological Survey, on the staff of which he served uninterruptedly for well-nigh 43 years, during the last seven of which he was Director, being further honoured with the title and office of Councillor of the Imperial-Royal Court.

For twenty-five years Stur took a very prominent share in the

field-work of the Imperial-Royal Geological Survey, and was busied with geological surveys in almost every district of the Austro-Hungarian monarchy. From that period dates a long series of scientific papers, mostly published in the Annuals (Jahrbücher) of the Survey, and many of these may be regarded as establishing the bases of the geological exploration of the Empire.

In addition to his geological acquirements, Stur possessed excellent training in and good knowledge of botany; and so we may easily conceive that, next to his geological field-work, palæobotany should form his favourite study; and later, when, owing to his promotion to the post of Vice-Director, he had bidden farewell to work in the field, he devoted himself entirely to the investigation of fossil floras, in particular those of the Culm and Carboniferous formations. An eloquent testimony of his unceasing activity in this direction is afforded by the exhaustive papers on the 'Culm Flora' and the 'Carboniferous Flora of the Schatzlar Beds,' published by him in the Transactions (Abhandlungen) of the Imperial-Royal Geological Survey (vols. viii. & xi.).

When, in the year 1885, Fr. von Hauer was appointed Curator of the Imperial-Royal Museum of Natural History, Stur succeeded him in the Directorship of the Imperial-Royal Geological Survey, and fulfilled with zeal and self-sacrificing devotion the duties of this post for very nearly eight years, until a rapidly developing malady of the heart compelled him to request his transfer to the retired list. This request was granted on the 21st October, 1892, together with a flattering distinction in the shape of the Knight's Cross of the Order of Leopold. But retirement did not bring tranquillity to Stur, now become grievously ill, and death released him from his sufferings on the 9th October, 1893, in the 67th year of his age.

Pierre J. Van Beneden, Foreign Member, was born at Malines on the 19th December, 1809, and received his early education there. Subsequently he studied with a chemist, M. Stoffels, who strongly imbued his pupil with a taste for zoology in addition to other scientific pursuits. In 1831 Van Beneden went to Louvain to pass his examination in Natural Science, obtaining the title of doctor after a year and a half at the University, during which period he continued to occupy himself with zoology, in virtue of his office as Curator of the University collections, which he arranged most thoroughly.

In order to complete his education Van Beneden spent the years 1834 and 1835 in Paris, where he established relations with those

who cultivated zoological science, and about this period he travelled in many parts of France and also in Italy for the purpose of gaining experience, being especially interested in marine biology. On returning to Belgium, after an appointment at Ghent which led to nothing, he was installed Professor of Zoology and Comparative Anatomy in the University of Louvain. This was in 1836, and he held that post, as a teacher of science, without interruption, to the day of his death, a period of 57 years. In 1865 he undertook to teach palæontology, and continued to give lectures in that branch of science until the end of his life.

Essentially a zoologist, Van Beneden was an indefatigable worker, including most branches of the animal kingdom within the range of his studies. His Academic publications, which were exceedingly numerous, do not often deal with palæontological subjects; but he would occasionally write on fossil Cetaceans from the Antwerp basin, or on the tooth of a fossil seal from the Crag of that district, sometimes extending his notices of fossil Cetaceans as far as Croatia. Amongst his non-Academic work may be mentioned his Report on the palæontological collections of the University of Louvain, published in 1867; a note on the Bats of the Mammoth period as compared with those of the present, in the British Association Reports for 1871; and on a new fossil bird from the caverns of New Zealand. His most important palæontological work probably was his description of the fossil bones of the neighbourhood of Antwerp, with copious illustrations. This appeared in four parts in the 'Annals of the Royal Museum of Natural History of Brussels,' the first having been published in 1877 and the fourth in 1885.

In the following year was celebrated the jubilee of Van Beneden's professorship under the honorary presidency of De la Vallée Poussin, whose admirable address on the occasion did no more than justice to the attainments and career of his illustrious colleague. In 1888 Van Beneden was elected a Foreign Member of this Society, being at that time also an honorary LL.D. of the University of Edinburgh. But the honours and acknowledgments which were bestowed so freely on this veteran zoologist in no wise caused him to relax his educational efforts, as we find him giving his latest lecture on the 20th December, 1893, or less than three weeks before his death, which occurred at Louvain, on the 8th January last, at the age of 84.

ON SOME RECENT WORK OF THE GEOLOGICAL SOCIETY.

Part II.

In continuation of the subject of the preceding Anniversary Address it becomes my duty, on the present occasion, to attempt some notice of a portion, at least, of the numerous papers contributed within the septennial limits, which were left untouched last year. These I would roughly divide into two groups.

In the *first group* are placed papers relating to the Newer Palæozoic Rocks, the Older Palæozoic Rocks, and the Fundamental Rocks, which bear upon the geology of the British Isles or their immediate vicinity. With these will be associated a large series of papers on General Petrology, dealing chiefly with igneous and metamorphic rocks, though I shall not attempt to touch upon matters which are, in the main, petrographical.

In the *second group* are numerous papers which may be roughly classified under the following headings: *Miscellaneous Geology, Foreign and Colonial*; *Miscellaneous Invertebrate Palæontology*; *Palæobotany*; and lastly *Dynamical Problems*. This group of subjects is so varied and so large that it would be impossible, within the limits of an address, to deal with it in anything like a comprehensive manner. Nevertheless, many of the papers are of great value; as, for instance, 'The Contribution to the Geology and Physical Geography of the Cape Colony,' by Prof. Green; 'The Geology of the Wengen and St. Cassian Strata,' by Miss Ogilvie; 'The Leaf-beds and Gravels of Ardtun in Mull,' by Mr. Starkie Gardner; not to mention others of equal interest. Before proceeding, therefore, to a more detailed consideration of the first group of papers, I submit a kind of synopsis of the second group under the headings above indicated.

Miscellaneous Geology, Foreign and Colonial.—This is of course a somewhat exhaustive division, comprising about a score of papers, which deal with many subjects in different parts of the world. Thus, we have had several communications respecting Africa. Indeed it is scarcely too much to say that the outlines of the geology of the 'Dark Continent' are by degrees being made known; and we may hope that, when Mr. Gregory has time to tell us the story of Mount Kenia, the Geological Society will be in possession of further details respecting a region which is now attracting so much attention. I have already alluded to Prof. Green's paper, where he gives a

summary of his views as to the probable geological history of South Africa, concluding that, since the great uplift of the country took place, that region has probably continued dry land to the present day, "for the scraps of Jurassic, Cretaceous, and Tertiary formations that it possesses lie close to the coast and were apparently formed at no great distance from the shore."

These words bring us to the consideration of Mr. Baron's paper on Madagascar, where the author tells us that sedimentary rocks occur mainly on the western and southern sides of the island. The relation of these to each other has not yet been determined; but judging from the fossils it would seem that the following formations are represented, viz.:—Lias, Lower Oolites, Oxfordian, Neocomian, Upper Cretaceous, and Eocene, whilst Recent Deposits fringe the coast and are largely developed on the southern part of the island. That portion of Madagascar which faces the Indian Ocean is represented as consisting of crystalline rocks with some volcanic ones. Hence, all the Neozoic beds above detailed must have been deposited within the area of the Mozambique Channel; nor do the eastern shores of the island furnish us with any evidence of what kind of rocks the fabled Lemuria consisted.

Reverting once more to South Africa, I may remind you that Mr. Penning, in a 'Contribution to the Geology of the Southern Transvaal,' directed attention more especially to the relation of the Gold-fields to each other, and to the high-level Coal-field of that region. He at the same time submitted a classification of the sedimentary rocks, dividing the high-level Coal-field into the Kimberley Beds and the High Veldt Beds, both of which he conceived to be of Oolitic age: upon this point it must be admitted there is considerable difference of opinion. The Witwatersrandt Series and associated beds he considered to be of Devonian age. Moreover, he expressed his opinion that the region had been under glacial influences during the long period which intervened between their deposition and that of the coal-bearing rocks of the High Veldt. These latter he considers to be of fluviatile origin, and he concludes that there has been a continuity of subaerial denudation from the close of the Oolitic period until the present time.

Some of the details of this paper were criticized, especially by Mr. Walcot Gibson and Mr. Alford. The former of these gentlemen subsequently communicated a paper on the 'Geology of the Gold-bearing Districts of the Southern Transvaal,' wherein he concludes that the gold-bearing conglomerates of the Witwaters-

randt district, with their associated quartz and shales, form one series, which has undergone a considerable amount of metamorphism. This series is much newer than the crystalline rocks on which it rests, since the gold-bearing conglomerates have been formed mainly at the expense of the underlying granites and gneisses, which are largely threaded with auriferous quartz-veins. As regards stratigraphical arrangement, the entire series associated with these gold-bearing beds has been thrust over the gneisses. Consequently, the beds do not seem to be contained in a simple basin; but, as was pointed out by Prof. Lapworth, it is probable there has been overthrusting and shearing along the edges of the basin, and possibly repetition in its interior, so that the actual thickness of the beds may not be very great. Mr. Gibson observes that subsequent to these movements the strata were injected with basic igneous material, and much of the country was flooded with lavas of a similar character.

Mr. Attwood, who has had considerable experience in gold-fields and their surroundings, stated that this district bore no resemblance, geologically speaking, to anything hitherto discovered and was therefore of special interest. He did not think that the gold in the quartzites and conglomerates could be called alluvial gold, as suggested by Prof. Green, because the metal is reported to be found in a fine state of division, whilst in all true alluvial deposits it is found of various forms and sizes. On the whole, Mr. Walcot Gibson was somewhat reticent as to the origin and method of deposit of the gold, but Mr. Alford stated his opinions on these points rather more freely, whilst allowing that the subject was an intricate one. The gold, he said, occurred in the matrix of the conglomerate and seldom in the quartz-pebbles, and, although the conglomerate-reefs were by no means regular in gold-bearing value, that value appeared to be greater where the beds had a high angle of dip and were in proximity to intrusive igneous rocks. For a further expression of Mr. Alford's views on this curious formation reference may be made to a work of his which has been lately published.[1] As it is admitted on all sides that the Witwatersrandt Series is one of exceptional character, I may be pardoned for having dwelt upon the subject at some length.

African geology has been further enriched by an interesting communication from Prof. Valentine Ball 'On some eroded Agate-pebbles from the Soudan,' which were collected by Surgeon-Major

[1] 'Geological Features of the Transvaal,' London: Stanford, 1891.

Greene. To the British occupation of Egypt we likewise owe some 'Notes on the Geology of the Northern Etbai or Eastern Desert of Egypt, with an account of the Emerald Mines,' by Mr. Ernest Floyer. This gentleman enjoyed exceptional advantages in the examination of a highly interesting district, which is difficult of access under ordinary circumstances. His conclusions as to the relations of the crystalline to the sedimentary series are somewhat at variance with those of the majority of previous authors, who have described adjacent districts in Egypt and the Sinaitic peninsula. As regards the matrix of the emerald in these ancient and now abandoned mines, we have the authority of Mr. Rudler that it appears to be a biotite-schist, more or less talcose, the mode of occurrence being somewhat similar to that of the emeralds of Siberia, where the mineral is associated with mica-schist. In 'Notes from the Nile Valley,' by Messrs. Johnson and Richmond, the information concerning the region south of Assouan is of considerable interest, though the intrusion of the granite into the sandstone, like a similar statement by Mr. Floyer, opens up new views as to the geology of these regions. In reference to this and other questions, we have the conclusions of Prof. Hull on the geological features of Arabia Petræa and Palestine, an outline of which was lately offered to the Society.

Under the heading 'Miscellaneous Geology' I would further draw attention to several interesting papers on Metalliferous Deposits—such as a paper by Mr. Attwood on the Auriferous Tracts of Mysore, a paper by the late Mr. Becher on the Gold-quartz Deposits of Pahang, one by Mr. Power on the Pambula Gold Deposits, and two papers by Mr. Collins on the Sudbury Copper Deposits and on the Geology of the Bridgwater District—both localities in Canada. Furthermore, there is a paper by Messrs. Hughes and Bonney on the Obermittweida Conglomerate, one by Mr. Lister on the Geology of the Tonga Islands, and one by Prof. Hull on the Physical Geology of Tennessee. Mr. Cooke tells us about the Marls and Clays of the Maltese Islands, Lieut. Frederick writes of certain islands in the New Hebrides, and finally there is the admirable paper, to which I have already alluded, by Miss Ogilvie on the Geology of the Wengen and St. Cassian Strata.

Miscellaneous Invertebrate Palæontology.—There are a score of papers which may be thus classified, dealing with siliceous organisms, with corals, crinoidea, bryozoa, ostracoda, and cephalopoda.

Messrs. Duncan, Hinde, Bather, Gregory, Sharman, Newton, Waters, Rupert Jones, Shrubsole, and Buckman have all been contributors to this branch of science. Most of these matters are for the consideration of specialists, and would come more directly under the cognizance of a President who was himself a general palæontologist. I venture, however, to draw your attention to the valuable work of Prof. Rupert Jones amongst the Entomostraca. He has described and illustrated in two papers Palæozoic ostracoda from North America, Wales, Ireland, France, and the Bosphorus, showing in particular the wide distribution of some of the species. Two more well-illustrated papers have been devoted to Palæozoic ostracoda from Westmoreland and the Girvan district, and on this occasion the Senior Secretary expressed his obligations for the trouble which the Author had taken in studying these obscure fossils from the Cross Fell inlier. During the present session, as you will remember, Prof. Rupert Jones assisted Messrs. Andrews and Jukes-Browne in determining certain ostracoda from the Vale of Wardour with results which might almost be deemed revolutionary. We hope, also, to see his latest contribution 'On the Rhætic and some Liassic Ostracoda of Britain' published in the May number of the Quarterly Journal.

Palæobotany.—Although there are a few short notices by other authors, the only contribution of any magnitude under this heading is one by Mr. Starkie Gardner 'On the Leaf-beds and Gravels of Ardtun in Mull,' with notes by Mr. Cole. This paper is, in the main, a redescription of the beds which were discovered by the Duke of Argyll about 43 years ago, and of their contents. One of the Author's objects was to prove that instead of belonging to the Miocene these floras are of Eocene age, and in fact older than the Thanet Beds. Summarizing their contents, it appears that only two vascular cryptogams are known, whilst among the gymnosperms *Ginkgo* is exceedingly abundant, associated with *Podocarpus* and *Taxus*. There are no monocotyledons beyond a liliaceous-looking leaf and a few reed-like stems. The dicotyledons are abundant, the collections being said to include more than 30 distinct species, most of them so adequately represented that the range of variation in the leaf is practically ascertained. Some remarkably well-preserved specimens from the Limestone of Ardtun are figured in the accompanying plates, which were executed by Mr. Gardner himself.

It remains for the students of fossil botany to determine how far this analysis, which was extended to the plant-bed at Atanekerdluk in Greenland, can be substantiated. Meanwhile, the Author contended that the identification of the above flora with the Miocene plants of Europe was groundless, or only applicable to such prevailing types of leaves as are common to widely distinct genera, and which occur in floras recent as well as fossil. He held that the resemblance and even identity of the best characterized forms with the older Eocene plants had been ignored. The most strongly marked types of Greenland, which also recur in Antrim, are met with in the Heersian of Gelinden and on no other horizon. These amply suffice to fix the date of the Antrim flora, whilst that of Mull is regarded as somewhat older. Independently of positive evidence, the absence of any late Tertiary types, even of the Leguminosæ which abound as low down as the Reading Beds, is held by Mr. Gardner to indicate their antiquity.

Dynamical Problems.—There have been two papers by Mr. Charles Davison 'On the Movement of Scree Material,' one by Mr. Oldham 'On the Law that Limits the Action of Flowing Streams,' one by Mr. Barlow 'On the Horizontal Movements of Rocks,' and possibly some other papers which might come under this heading, such as Mr Davison's notice of the Inverness Earthquake. A valuable communication from Prof. Spencer 'On the Origin of the Basins of the Great Lakes of America' would seem also to find a place here.

It is now time to call your attention to the four principal subjects constituting the first group—which I propose to consider somewhat in detail. These are *The Newer Palæozoic Rocks*, *The Older Palæozoic Rocks*, *The Fundamental Rocks*, and *General Petrology*.

The Newer Palæozoic Rocks.

Coal-measures.—The Carboniferous System has not yielded us any important stratigraphical papers of late years; consequently such matters as have been brought to the notice of the Society relate to details of varied character.

Thus, for instance, the question of boulders found in seams of coal has been raised by two Authors, viz. Mr. James Ratcliffe and Mr. John Spencer. The former indicated a series of boulders, ranging from 4 to 166 lbs. in weight, which had been embedded in the roof of a coal-seam in the Manchester district, similar boulders

having been described from other English coal-fields. Those noted by Mr. Ratcliffe were principally of quartzite, but boulders of granite have also been found. The principal facts to notice are, that the rocks are foreign to the district, that the boulders are isolated, and occasionally even striated (?), and that they seem to be waterworn and rounded. Sometimes they occur in the bed of coal, but more frequently at its junction with the overlying rock. Some importance attaches to these boulders, both on account of the general rarity of pebbles throughout the Coal-measures and also because of the speculations as to the possible transporting agent.

It is certainly a curious fact that, if a few hundredweights of rock are found in an isolated position in any of the sedimentary series, the action of ice is sure to be invoked to account for the phenomenon. This, for instance, is what Mr. Spencer did in his short notice 'On Boulders found in Seams of Coal,' though we may well believe that transport by the roots of trees or floating vegetation of some sort is an equally good, if not, indeed, a more probable explanation. It has been suggested that, in the case mentioned by Mr. Ratcliffe, the boulders may have come from some of the pre-Carboniferous conglomerates of the North of England or of Scotland. As the boulders have all the appearance of having been dropped quietly upon the top of the coal, this would imply some depth of water overhead, whatever may have been the agent of transportation. In the Carboniferous Limestone of the neighbourhood of Dublin, Prof. Ball has lately pointed out that *angular* fragments of granite and other hard rocks have been found. Whilst rejecting the view that they had been transported by ice, he maintained that they need not necessarily have been carried by land plants, but that they might have been torn from the sea-floor by marine algæ. He cited the case of a sandy beach at Youghal, where the shore is strewn with limestone-fragments which had been conveyed by seaweeds thrown up after storms from submarine banks. Attention was also drawn to Anson's mention of the occurrence of seaweeds loaded with stones far out at sea.

Some interesting facts in connexion with coal-seams were recorded by Mr. Hendy in his short paper on a 'wash-out' in one of the Derbyshire collieries, the nature of the phenomena being aptly illustrated by a series of sections drawn to scale. It has frequently been suggested that such 'wash-outs' are due to faulting, but in this instance, at least, such can hardly have been the case, since the underclay and underlying sandstone are undisturbed,

although in one instance the underclay is seen to have been cut through by the denuding agent. The space of the 'wash-out' is filled up by sandstone. This is clearly an instance of contemporaneous erosion, and the 'wash-out' may actually represent one of the river-beds of the fen in which the coal accumulated. In this case one third to one half of the coal is said to have been re-deposited in different places on the sides, the remainder having evidently been carried away, thus pointing to a kind of intermittent action of the water.

In a paper on the Formation of Coal-seams, Mr. Gresley, from evidence gathered chiefly in the Leicestershire and South Derbyshire coal-fields, is disposed to contest the orthodox view of growth *in situ*. Without myself venturing to express an opinion upon this point, it seems to me that the experience of mining engineers and others connected with the working of coal is of great importance. It sometimes happens that professional men of this sort, though possessed of valuable information, are unable to put it into a geological form, and require, as it were, an interpreter. But such is not Mr. Gresley's case, and I venture to think that an abstract of his arguments is worthy of attention.

In considering the relations of the fire-clays to the coal-seams, he points out that such fire-clays, containing *Stigmariæ* and root-like fossils, occur in other positions than that of an underclay to coal; that the thickness of an underclay bears no proportion to that of the coal-seam resting upon it; and that the underclay is usually divided off from the coal-seam by a true bedding-plane, nor is there any merging of one formation into the other. Secondly, when considering the behaviour of *Stigmaria*-roots, he points out that a considerable proportion of the underclays do not contain *Stigmaria*-roots at all, though they seldom fail to reveal the presence of thin, grass-like, fossil markings. But when *Stigmariæ* do occur in the underclays, they do not, as a rule, pass upwards into the coal. Moreover, when erect fossil stems or stools of trees are met with, they are generally either resting upon or at no great distance from the tops of coal-beds; though the best examples, such as the fossil trees at Clayton and Bradford, have occurred in beds far removed from coal. He concludes that the general absence of erect fossil tree-stems in underclays is an argument against a growth *in situ* of coal, at all events from trees. Thirdly, in considering the question of lamination, he asserts that the laminated character of coal affords no evidence that the coal-forming plants grew upon the

spot. If there had been any great number of upright trees they would have interfered with the parallel structure of the coal, nor is it probable that this interference would have been obliterated by pressure or by metamorphism. Where are the trees from which the macrospores of spore-coal were shed? The partings of coal in seams have yet, he thinks, to be explained.

Some other considerations were advanced by Mr. Gresley of a more general nature, such as the presence of boulders and other foreign bodies in the underclay and coal-beds; whilst aquatic mollusca and fishes are found in the coal itself. He points out likewise that marine conditions prevailed, if not during the accumulation of many of our coal-beds, yet without doubt immediately afterwards, as may be inferred from the presence of marine fossils and brine in the coal.

Let us now turn to a paper by Mr. Kirkby on the occurrence of marine fossils in the Coal-measures of Fife. These are divided into two series, viz. the Lower Beds with workable coals (d^5 of the Geol. Survey) and the Upper Red Beds ($d^{5'}$ of the Geol. Survey). The *marine bed* lies almost at the top of the former series, having been proved at two localities. Together with the remains of some of the ordinary Coal-measure fishes there occur, in a dark-coloured shale, specimens of *Discites* and *Orthoceras*, of *Bellerophon* and *Murchisonia*, and of *Productus*, *Discina*, and *Lingula*. One of these latter, viz. *Lingula mytiloides*, is also found along with *Discina nitida* in the Lower Permian limestone of Durham and Northumberland.

This author likewise proceeds to enumerate the occurrence of marine fossils in the Coal-measures of the West of Scotland, where they have been noted on no less than four horizons. He further illustrates his views by quoting Phillips's notice of the occurrence of *Aviculopecten*, *Posidonomya*, *Goniatites*, and *Orthoceras* in the roof of one of the Ganister Coals in the West Riding of Yorkshire, and alludes to the occurrence of brine both in the Lancashire and Staffordshire coal-fields.

In speculating on the conclusions which may be adduced from the above facts, Mr. Kirkby speaks of inroads of the sea bringing back species of shells and even crinoids, such as had existed in the Carboniferous Limestone ocean of an earlier period, and thus infers that the sea itself could not have been far off during the deposition of the Coal-measures. These intercalated marine beds, he says, seem easier of explanation when the formation is looked upon

as deltaic; under such conditions everything observed in the palæontology of the strata can be accounted for, whether the indications be of dense vegetable growth or of vegetable drift, and also whether the animal life presents a freshwater, brackish-water, or marine *facies*. On the whole, he strongly questions the merely lacustrine origin of the Coal-measures.

On these points, again, we have the very recent testimony of Dr. Wheelton Hind, whose paper, though mainly palæontological, is eminently suggestive. In writing of the affinities of *Anthracoptera*[1] and *Anthracomya* this author concludes to place the former genus in the family Mytilidæ, whilst *Anthracomya* is classed with the Unionidæ. The palæontological details are fully worked out, and present points of considerable interest. There is no evidence that the shells of *Anthracomya* represent burrowing species, since they are never found lying at right angles to the lines of stratification. The shells approximate closely to *Anodon*, but they lack the eroded obsolete beaks, the supplementary anterior-adductor muscle-scar, and the equal valves of this form.

Salter, he observes, believed that the beds in which *Anthracosia*, *Anthracoptera*, and *Anthracomya* occur were of marine or of highly brackish-water origin. Doubtless, remarks Dr. Wheelton Hind, there are truly marine beds in the Coal-measures, and these contain a characteristic marine fauna, yielding *Productus*, *Spirifer*, *Lingula*, *Discina*, *Aviculopecten*, *Posidonia*, *Edmondia*, *Sanguinolites*, *Orthoceras*, *Goniatites*, and *Nautilus*, not only towards the base as in the Ganister beds, but also much higher up in the series as developed in North Staffordshire. In none of such beds do *Anthracosia*, *Anthracoptera*, and *Anthracomya* occur; but, on the other hand, these genera are found associated with a peculiar fauna of fishes and reptiles, annelids and crustaceans, which have a close affinity with recent forms inhabiting fresh water, together with a flora of ferns, *Sigillaria*, *Calamites*, and *Lepidodendron*. The fact of typical marine fossils being found in a few beds of small extent, intercalated in the coal strata, seems to Dr. Hind to afford strong evidence that the rest of the beds were not marine. The general affinities of *Anthracoptera* and *Anthracomya* with recent freshwater shells afford strong presumptive evidence of the freshwater origin of the greater part of the Coal-measures, nor has any mixture of fluviatile and marine forms in the same bed come to his knowledge.

[1] It seems probable that Salter's genus *Anthracoptera* will have to give way to *Naiadites*, Dawson.

If we endeavour to draw any practical conclusions from the above-quoted papers as to the mode of formation of coal-seams, and also as regards the origin of the Coal-measures generally, we can scarcely do better, in the first instance, than accept the suggestion of Mr. Kirkby that the Coal-measures both in Scotland and the North of England represent, in the main, deltaic formations rather than lacustrine ones. There is but little novelty in the recognition of marine fossils in the Coal-measures, but the facts required to be brought forward more prominently, and especially to be sifted as they have been by Dr. Wheelton Hind. When we read of incursions of the sea we are reminded of what occurs from time to time in all deltaic or estuarine deposits; and these facts may to a certain extent be paralleled in the Jurassic coal-field of Yorkshire, and even in the Purbecks, though in the latter case without coal. Of course, in such areas there would be plenty of freshwater lagoons or lakelets, with their peculiar fauna; and Mr. Gresley need not be surprised at fish-remains occurring in coal, even on the supposition that a large portion of it represents local growths. The fens which border the Wash consist very largely of peat formed from local growth, and shallow basins in this peat, such as Whittlesea Mere, used to be full of fish. There must be many a pike buried in the peat of that now-drained fen ready to be converted into a 'fossil fish in coal' under the requisite conditions. Again, it is not unlikely that the old Carboniferous fens were occasionally permeated by channels, which would in times of flood have connexion with a bigger river. This view might help to explain the flotation of spore-cases, and even the transport of boulders from afar, which, having journeyed for some distance on floating vegetation, were quietly dropped from the surface of some calm and shallow pool upon the peat beneath. In conclusion, we may feel sure that just as the nature of coal varies so did the methods by which it was produced.

Coal in the South-east of England.

Just about seven years ago Mr. Whitaker contributed some further notes on the results of deep borings in Kent. This supplementary paper was brought before the Society owing to the fresh light which a boring at Dover at that time seemed to throw on the underground geology of the London Basin. The boring in question was made at the convict prison, and, having been abandoned at 931 feet from the surface, failed to reach the Palæozoic rocks.

Mr. Whitaker, however, concluded his paper with some valuable remarks on the best site for additional borings at Dover in the hope of piercing the Coal-measures. He mentioned with especial satisfaction the accounts of the trial-boring then being made at the foot of Shakespeare's Cliff, being even then animated by the conviction that the day would come when coal would be worked in the South-east of England.

Since this paper was read no further communication has been made to the Society with reference to boring at Dover, though you are well aware that considerable progress has been made in this direction through the exertions of Mr. Francis Brady, Chief Resident Engineer of the South Eastern Railway, and his able coadjutors.

That gentleman, in June 1892, published an interesting report of the Dover Coal-boring,[1] at which date the depth attained was about 1875 feet. In December of the same year he had the satisfaction of being able to forward a telegram to Sir Edward Watkin to the effect that a 4-foot seam of good bituminous coal had been proved at a depth of 2180 feet (the telegram says 2222 feet). As this report deals with a question which had already been raised by Mr. Whitaker in the Quarterly Journal, we are justified in considering the evidence which it affords of the development of the Coal-measures in the South-east of England.

To the Report is appended a vertical section giving full particulars as known up to December 1892, since which date, I am given to understand, no greater depths have been proved. The boring, it will be remembered, starts in the Grey Chalk, and passes through 259 feet more of Upper Cretaceous rocks, inclusive of the Gault. The Lower Cretaceous rocks, including the Lower Greensand, the Wealden and Hastings Beds, are estimated at no more than 241 feet, whilst the Jurassic rocks, including Upper, Middle, and Lower Oolites, with Lias at the base, are held to account for 613 feet. The total thickness of Mesozoic rocks, or 'dead beds,' bored through is 1113 feet, at which point the Coal-measures are struck.

As we are not dealing with the Mesozoic rocks on the present occasion, the above estimates may pass without criticism, our attention being fixed on the details of the 1068 feet of Coal-measures revealed by the boring-rod. In this series there are about 12 seams of coal, ranging from 1 to 4 feet in thickness, and terminating

[1] 'Dover Coal-boring.—Observations on the Correlation of the Franco-Belgian, Dover, and Somerset Coal-fields.' (?) London, 1892.

in the 4 feet of good bituminous coal, which has so raised the expectations of the explorers. The beds are believed to be nearly horizontal, and, as they contain 1 foot of coal to about 50 feet of measures, they compare favourably with those in the Radstock field, where the proportion is 1 foot of coal to about 80 feet of measures. The seams proved are stated generally to have the same quality as the rich bituminous coals of Mons and Bruay, and do not resemble the dry coal of Marquise, which is supposed to be of earlier date. Messrs. Zeiller and Breton, having studied the fossil plants found in these Dover Coal-measures, are of opinion that the Dover coal belongs to the upper portion of the Nord and Pas-de-Calais coal-basins. Mr. Brady maintains, therefore, that not only is the quality of the Dover coal likely to be found equal to some of the best Belgian coals, but that the beds of the Pas-de-Calais increase in thickness to the westward, both conclusions being contrary to the views maintained before the Coal Commission in 1869.

A shaft is now being sunk, but this, according to Mr. Etheridge, has not yet progressed beyond the Cretaceous beds; hence no further information relative to the Coal-measures has, so far as I know, been forthcoming from this quarter. We are, however, naturally led to speculate on the general question of coal in the South-east of England from the facts recently ascertained. Prof. Prestwich, it will be remembered, in his Report of 1871 to the Coal Commission, in the first place spoke of the original coal-trough as having been broken up into separate basins; and, secondly, in forecasting the probable direction of the underground (sub-Mesozoic) axis, he suggested two alternatives, roughly north or south of the Thames. Each view probably has its respective advocates. The Eastern counties have formed a 'Coal-boring and Development Association,' and although the prospects of finding coal in the East Anglian Palæozoic area are not very bright, it is just possible that the adventurers may strike the Coal-measures in one or other of the narrow synclinal troughs running east and west in Essex, Suffolk, and Norfolk. For my own part I am disposed to agree with Mr. Brady that, in further explorations for coal beneath the Secondary rocks, the southern alternative of Prestwich is the one which holds out the greatest hopes. It will be tolerably safe to assume that future operations should follow a nearly direct westerly course from Dover towards Bristol. These conclusions are mainly in accord with those lately expressed by Prof. Boyd Dawkins[1] at the

[1] Friday evening lecture at the Royal Institution, June 1890. 'Nature,' vol. xlii. p. 319.

Royal Institution, where he commented on the accuracy of Godwin-Austen's views as to the range of the Coal-measures along the line of the North Downs. It might not, perhaps, be an unmixed advantage to bring more coal to London than finds its way there already; but if something in the nature of a coal-basin exists within hail of the metropolis, it is quite as likely to be found between Croydon and Reigate as anywhere else. If the Board of Trade could be persuaded to bore at suitable intervals along a line connecting those two towns, geological science would certainly be a gainer, and Surrey as well as Kent might be proved to have its coal-field.

Carboniferous Limestone.—There are no stratigraphical papers dealing with this formation, but we have a series of palæontological papers by Miss Donald; whilst Mr. Wethered gives us the results of the examination of the insoluble residues obtained from the Carboniferous Limestone of Clifton.

In her first paper Miss Donald discusses the genetic relations of the shells hitherto grouped under *Murchisonia*, more especially in connexion with the sinuated genus *Pleurotomaria*, and the possibly, in some cases, sinuated *Turritella*. The second paper is mainly occupied in discussing some of the genera or sections into which *Murchisonia* has been broken up, with more especial reference to *Goniostropha*. In the third paper the Author goes a step further by founding the section *Hypergonia*, to include such forms as *Murchisonia quadricarinata*, and other well-known species, where the sinus is situated above the angle. In this paper she likewise notes the sections *Cœlocaulus* and *Cerithioides*, giving a full description with figures of *Cerithioides telescopium*, a fossil so named by Haughton under the impression that it was a Pyramidellid, closely related to the recent *Cerithium telescopium*. Miss Donald proposes to retain the name *Cerithioides* for a section of *Murchisonia*, in which this species might be placed until more is known of its affinities.

Beyond the fact that it relates to the Carboniferous Limestone, Mr. Wethered's paper covers entirely different ground. Incidentally the Author classifies the series at Clifton, which has a thickness of 2700 feet, for purposes of reference, but it is the microscopic examination of the insoluble residues and of rock-sections to which I must direct attention. Rocks with from 1 to 80 per cent. of matter insoluble in hydrochloric acid were examined, the impurities consisting mainly of detrital quartz, with here and there a few

grains of felspar, tourmaline, and zircon. In the main mass of the calcareous rock there is, of course, a less amount of detrital quartz, but the presence of micro-crystals of quartz, as also of amorphous and chalcedonic silica and of sponge-spicules, was indicated. The nature of the amorphous and chalcedonic silica in the limestone, and the relations of this silica to the small quartz-crystals, were also discussed. The latter were shown in some instances to possess nuclei of detrital quartz, and, where this is not the case, to have resulted from the crystallization of amorphous silica. The chief interest in this portion of the paper, as was remarked at the time, lay in the indications of a gradual passage from amorphous silica into chalcedony, and so into quartz, it being further observed that silica, in the rocks, has a tendency to pass towards the stable condition of that mineral.

Devonian.—In direct continuation of the last subject, I have to refer to another suggestive paper by Mr. Wethered on the Devonian Limestones of South Devon. In drawing conclusions from the examination of the insoluble residues of examples collected in the neighbourhood of Torquay and elsewhere, he observes that, whilst well-rounded grains of detrital quartz were found in the Carboniferous Limestone of Clifton, no such detrital grains can be discovered in the Devonian Limestone residues examined by him. Further, in discussing the occurrence of micro-crystals of quartz he refers to an observation by Prof. Sollas that such crystals are left on dissolving Devonian Limestone, containing the so-called *Stromatopora concentrica*, from Kingsteignton. Yet Mr. Wethered doubts the organic (sponge-spicule) origin of these micro-crystals of quartz in the Devonian Limestones, since he has not met with any siliceous organisms, nor noticed any such process as that described in his previous paper. He is inclined to believe that these micro-crystals of quartz have originated from the silica of decomposing silicates, and, as a case in point, he notes that the crystals of quartz are the most numerous in those limestones which have undergone the greatest amount of alteration through crystallization.

Mr. Wethered allows that the conclusions drawn from the microscopic examination of the Devonian Limestones are not very satisfactory, so far as structure is concerned. Yet he has obtained ample evidence that these limestones have been built up by the remains of calcareous organisms, though the outlines of structure have, for the most part, been obliterated by molecular changes. It

is well known, he observes, that in more recent limestones the interstices of the constituent organisms are generally occupied by a quantity of calcite. In this case the original calcite of the limestone can easily be recognized by its large clear crystals; whilst, on the other hand, the altered portion of the limestone is represented by small crystals in aggregates, and these are usually stained by iron oxides. So far, he says, as the evidence warrants a conclusion being drawn, the Devonian Limestones of South Devon appear to have chiefly originated from corals, crinoids, ostracoda, stromatoporoids, and fragments of shell; some limestones even representing coral-reefs, others coralline débris; the Goniatite Limestone alone contains foraminifera. There is little, perhaps, in this which has not previously been indicated by macroscopic evidence, but it is satisfactory to find that evidence confirmed by the microscope.

In discussing the more distinctly mineralogical questions, the Author alludes to the occasional occurrence of rhombohedra of dolomite. The micas, he thinks, may be of detrital origin, but this is by no means certain. Minute crystals, referred to as 'microlithic needles,' resemble 'clay-slate needles,' but are not always straight; they occur in every fine residue, and as inclusions in siliceous and micaceous flakes. The siliceous fragments which enclose them frequently contain many liquid inclusions. These points were well illustrated, and the investigations generally were regarded as of great value in illustrating the history of mineral growth and development. Dr. Sorby, who was present at the discussion, referred to the fact that he had himself been led to study the Devonian Limestones of Devonshire chiefly on account of the valuable evidence they afford in connexion with the cause of slaty cleavage. He thought that, taken as a whole, no group of limestones presents a greater range of character; for not only must their original nature have varied extremely, but the amount of change due to chemical reactions and to pressure had, in many cases, been considerable.

The South Devon rocks have, in addition to this paper by Mr. Wethered, formed the subject of two extremely interesting communications to the Society. In the first place, there was the late Mr. Champernowne's notice of the Ashprington volcanic series on the banks of the Dart below Totnes. This was a posthumous paper, which we owe, in a great measure, to the care and solicitude of Sir Archibald Geikie, and as he has dealt with the subject fully in one of his Presidential Addresses, there is no need on the

present occasion to go into further details. Mr. Ussher, who is the author of the other paper referred to on the Devonian rocks of South Devon, in alluding to Mr. Champernowne's work, writes as follows :—"The existence of contemporaneous volcanic action—the definition of the Ashprington series and of sporadic evidences of local vulcanicity outside its borders—the correlation of the Ashburton limestone with that of Newton and Ipplepen,—and palæontological contributions, adding to our knowledge of the Middle and Lower Devonian, stand prominently forth amongst the labours of my deceased friend.... So the present communication must be taken as the outcome of my friend's life-work in Devonian geology, and will, I trust, form not an unfitting tribute to his memory."

There can be no doubt that it has required in the past, and will yet require in the future, an immense amount of detailed observation to put together the pieces of that geological puzzle which exists in the region between Dartmoor and the English Channel. As remarked by the Director-General of the Geological Survey, dip and strike go for little in such plicated and dislocated countries. Indeed, we may say that without a palæontological key the history of the region could never have been deciphered. Unfortunately, in North Devon, where the stratigraphy of the Devonian rocks is less complicated, the differences of development are so considerable, more especially in the rarity of calcareous beds resulting from coral-reefs, and in the almost complete absence of contemporaneous volcanic rocks, that the requisite information can hardly be obtained. It is in less disturbed regions on the Continent, where the original development is similar to that of South Devon, that we must seek for comparisons, as Mr. Champernowne was in the habit of doing. Since his day an important event has occurred ; I refer to the autumn excursion of a party of the International Geological Congress of London, including Messrs. Gosselet, Kayser, and others, conducted by Mr. Ussher. Dr. Kayser embodied the results of his observations in a pamphlet,[1] to which I drew attention in my address to the Devonshire Association in July, 1889.[2] The following is an extract :—"Herr Kayser finds in South Devon a development which intimately approaches the West German. In the Upper Devonian of that region he recognizes nodular limestones with *Clymenia* (more typically developed at South Petherwin), 'Cypridinen-Schiefer,' Adorf Goniatite-limestone,

[1] 'Ueber das Devon in Devonshire und im Boulonnais,' Neues Jahrb. 1889, Band i. p. 179.

[2] Trans. Devonsh. Assoc. vol. xxi. p. 44.

Büdesheim-shales, and Iberg coral- and brachiopod-limestone. In the Middle Devonian he recognizes *Stringocephalus*-limestone, *Calceola*-limestone, *Calceola*-shales, and possibly also Goslar-beds. In the Lower Devonian he finds the Upper and Lower Coblenz stages, and 'Siegen Grauwacké,' especially represented by a small but typical fauna at Looe. This general agreement is further increased by the appearance of numerous 'greenstones,' which, just as in Nassau and the Harz, are accompanied by schalsteins."

Mr. Ussher's paper relates more particularly to the area north of the Dart and east of Dartmoor, and it is satisfactory to find that his views are fairly in agreement with those of Herr Kayser, the value of whose identifications he readily acknowledges. Although the lithological constituents of the Upper, Middle, and Lower Devonian beds are broadly distinguishable, yet there is no definite lithological boundary between the groups. The Lower Devonian is mainly indicated by the occurrence of sandstone and grit; but the upper beds are slates or shales passing without distinction upward into the Middle Devonian slates. In no part of the Lower Devonian of this district have igneous rocks been found. The Lower Devonian of the Torquay and Paignton areas is described with especial attention to the fossils, and the Author embraces the opportunity of correcting a mistake into which he, and latterly also Mr. Champernowne, fell with regard to the position of the Cockington Grits, which may, he says, be placed in the Lower Devonian on palæontological evidence quite as strong as any furnished by the Torquay promontory. He considers that at present the evidence is not sufficient to justify the subdivision of these beds into Upper and Lower Coblenzian.

The Middle Devonian is, of course, the most interesting series; and here I would remark that, in the Abstract of this paper, the sequence differs from that given in the Quarterly Journal. Assuming the latter to represent Mr. Ussher's final views, he makes the Ashprington volcanic series underlie the Middle Devonian Limestones (vol. xlvi. p. 493), thereby apparently endorsing the opinion expressed by Mr. Worth that, in the Plymouth district, the volcanic rocks were mainly below the limestone. Further on, however, he remarks that the Ashprington series may represent continuous or intermittent activity up to the middle of the Frasnian. In ascending sequence, then, the following is now held to be the development of Middle Devonian rocks in this area. At the base are the Eifelian slates, characteristically developed in Berry Park, bounded on the

south by the Ashprington volcanic series, and on the east by the Lower Devonian of Beacon Hill and Windmill Hill (Cockington Grits). The shaly 'Calceolen-kalk,' or Eifelian Limestone, which gradually comes on in the upper part of the series is frequently brought up in the limestone masses of Torquay and elsewhere by contortion. Fossils common in the Eifelian slates are *Atrypa reticularis*, *Streptorhynchus crenistria*, and *Spirifer speciosus*. Both by fossil and stratigraphical evidence the position of certain limestone patches in connexion with the Ashprington volcanic series is proved to coincide with the Eifelian Limestone, and we are thus supplied with a reliable date for the commencement of this phase of volcanic activity, viz., the later stages of the Eifelian deposition. This is also borne out by the absence of volcanic materials in the Lower Devonian and Eifelian Slate areas. How long it continued is not equally clear, but there seems, he says, to be evidence of vulcanicity in other areas in connexion with a great development of Middle Devonian Limestone.

Continuing the Middle Devonian sequence, we have now to consider the main mass of Devonian Limestone. Mr. Ussher says there is absolutely no line of demarcation between the upper horizon of the 'Calceolen-kalk' and the bedded limestones above, which are held to be on the *Stringocephalus*-horizon; hence their separate treatment is purely arbitrary. It would take up too much time to follow the interesting evidence, chiefly palæontological, adduced by the Author in connexion with the Torquay, Dartington, and Newton Abbot districts. In his summary he infers, generally, that the bedded limestones which succeeded the shelly and coralline bands, representing the Eifelian Limestone, became in places the bases for more uninterrupted coralline growth. This growth, he considers, was locally continuous to the earlier stages of the Upper Devonian period. In the meantime, proofs are not wanting that the accumulation of Middle Devonian Limestone took place contemporaneously with the Ashprington volcanic outbursts; so that, in the words of Mr. Champernowne with reference to the stratigraphical difficulties presented by that series:—"All these anomalous appearances are at the same time quite capable of being accounted for, if we consider what might take place in a reef district which was at the same time the arena of volcanic disturbance." That gentleman's experience, moreover, fully endorsed De la Beche's view that certain of the limestones are laterally replaced by slates.

With few exceptions, it is only of late years that Upper Devonian rocks have been demonstrated in this district, and even now Mr. Ussher does not think it possible to draw an arbitrary boundary in South Devon between Middle and Upper Devonian below the shaly Goniatite-limestones. Consequently, his generalized sequence in ascending order is:—Massive limestones, Goniatite-limestones and slates, Cypridinen-Schiefer (*Entomis*-slates). Speaking of the lower portions of the series (massive limestone), he states that Dr. Kayser's list from Lower Dunscombe quarry, below the Goniatite-beds, included *Rhynchonella cuboides* and other well-known brachiopods, such as might be held to infer a lower Frasnian horizon. As regards the Goniatite-beds themselves, it is interesting to note that there are traces of this fauna in the direction of Brixham; this is at Silver Cove, where the junction is said to be inverted, the thin beds of limestone occurring in their natural position at Galmpton Point. It would savour too much of local geology to enumerate the places where this horizon has been detected, and yet their number is likely to be increased, if we may credit Mr. Ussher that certain 'unfossiliferous' slates would reveal to a patient searcher traces of the Goniatite-fauna. Lastly, in the map of the distribution of the Devonian rocks between the river Teign and the Haldon Hills we notice, in the midst of a puzzling geological complex, a considerable development of the Cypridinen-Schiefer on both sides of the Teign, but more especially on the north. With the exception of the nodular limestones with *Clymenia*, mentioned by Dr. Kayser, this completes the Devonian succession in South Devon.

To sum up, we may say that if there is one point made clearer than another by the study of this region, it is that stratigraphy alone is inadequate to put together a geological puzzle such as South Devon presents: where beds, which were irregularly developed in the first instance, have been squeezed between granite-masses on the north and an axis of upheaval on the south. If I remember Mr. Champernowne's words correctly, matters are still worse on the other side of the Dart, while the difficulties about Tavistock and on the west side of Dartmoor generally are notorious. Mr. Ussher is quite correct in saying that the facts established in his paper have a much wider application than to the district described, since the identification of the Cockington beds as Lower Devonian relates to a large area between the Dart and Plymouth. It is significant that in a geological map of the south-western counties recently

constructed by Mr. Ussher[1] the whole of the great triangle which constitutes the southern lobe of Devon is coloured as Lower Devonian. Apart from the somewhat fanciful idea of including the Start rocks in this category, it is very much what we should expect from indications already made known before Mr. Ussher had seen fit to change his mind on the subject of the Cockington Grits. The great development of Lower Devonian beds in this maritime area, continued in a westerly direction through Looe and thence right across the heart of Cornwall, adds to the completeness of the broad synclinal which is the leading physical feature of the south-western peninsula.

The Older Palæozoic Rocks.

Silurian and Ordovician.—I presume that it is right to include the Arenig series with the Ordovician, these two systems or sub-systems thus constituting the upper division of the Older Palæozoic. We have had about half a dozen papers in this category. Of these, two by Messrs. Marr and Nicholson have reference to the North-west of England; there is a stratigraphical paper on the Llandovery rocks of the neighbourhood of Corwen by Messrs. Lake and Groom, and papers on special subjects by Prof. Rupert Jones and Mr. Wethered. There is also a note on the geology of the district west of Caermarthen from the pen of the late Thos. Roberts, wherein he records the discovery of the *Tetragraptus*-beds of Arenig age, which had not hitherto been detected south of the St. David's district.

Messrs. Marr and Nicholson's first paper relates to the Stockdale Shales, which extend across the main part of the southern half of the Lake District, parallel with the underlying Coniston Limestone series and the overlying Coniston Flags, with both of which they are conformable; *i. e.* they are conformable to the Ordovician beds below and to the Wenlock beds above, thus representing the two Llandovery subdivisions and the Tarannon Shales of the Welsh Border area. The Authors also correlate the Graptolite-zones with those of the Birkhill and Gala groups in the South of Scotland. Although the whole group, in the area examined, attains to no more than 400 feet as a maximum thickness, the Authors indicate something like seventeen zones or horizons, many of them distinguished by a particular graptolite. These Stockdale Shales are regarded as being divisible into a Lower group, viz., the Skelgill Beds, consisting

[1] Proc. Somerset. Archæol. Soc. vol. xxxviii. 1892.

mainly of dark graptolite-bearing shales, which alternate with lighter-coloured mudstones entirely devoid of graptolites except where they pass into the adjacent graptolitic shales. The Upper group (Browgill Beds) is nearly three times as thick as the lower one, having probably been formed much more rapidly, and consequently of less importance; it consists chiefly of green and purple shales with interstratified grit-bands and a few insignificant seams of dark graptolite-bearing shales. Although there is absolute conformity between the lowest beds of the Stockdale Shales and the highest beds of the Ashgill Shales, the palæontological break is complete, and it is at this point that the Authors draw the line of division between the Ordovician and Silurian systems.

One very singular fact in connexion with this enquiry, having a wide bearing on stratigraphical palæontology in general, is the remarkable recurrence of graptolitic and non-graptolitic beds so characteristic of the lower series. The subject of recurrent faunas is well-known in several formations, and in some cases is more or less due to changes, which partly indicate their nature by a difference in the character of the sediment. The Authors, and especially one of them, who has ably discussed this subject before the Cambridge Philosophical Society, are disposed to consider it due to climatic changes in the present case, which is certainly one of the most remarkable to which the attention of palæontologists has been drawn. There is another question in connexion with these beds to which they also draw attention, viz. Are the graptolites wholly absent from the trilobite-bearing mudstones, and *vice versâ*? The usual difficulty which attaches to the proving of a negative is naturally felt, though they conclude that there was, possibly, complete migration in some cases, whilst in others the forms may have lingered on in diminished numbers during the period that was unfavourable to their existence. In this latter case, they suggest that such a lingering on would be admirably qualified to bring about that variation in the creatures which would account for the marked contrast between the fossil contents of beds separated by only a few feet of intervening rock.

The Authors claim that the most important result of their researches is the additional evidence they have furnished of the value of graptolite-zones as a means of comparison of Lower Palæozoic rocks of distant areas. It is true that a suggestion was made to the effect that possibly the application of graptolitic as against trilobitic verniers might not produce the same results in the way of

correlation. Prof. Lapworth, as might have been expected, strongly endorsed the views expressed by the Authors. He looked forward to the day when the existence of these Graptolite-zones in the Lower Palæozoic rocks would be generally acknowledged, and that they would be employed as a basis for classification and mapping. He further remarked that the thin Moffat series of the South of Scotland represented the whole of the Llandeilo, Bala, and Llandovery formations in other regions. Although the general position of the Stockdale Shales with reference to other formations above and below was known previously, the Authors had now fixed their horizon from internal evidence. The zones they had detailed in the Lake District agreed with zones already established in the South of Scotland, Wales, and other countries. He commented on the small thickness of these Stockdale beds, but pointed out that they were represented by very great thicknesses of deposit elsewhere. Thus the Browgill or Upper Stockdale series had their equivalent in thousands of feet in the Gala group and the Tarannon; whilst the Skelgill, or Lower series, were represented by enormous thicknesses in Girvan and Central Wales. He considered that the Authors had accomplished a piece of work of the highest systematic importance, but further zone-work was required, and he predicted that it would be followed by a re-mapping of many areas.

The same Authors have made a further contribution to our knowledge of the Older Palæozoics in their paper on the Cross Fell Inlier, which is one of the stratigraphical features of the Eden Valley—representing a tract of Ordovician and Silurian rocks lying between the Carboniferous of the Cross Fell range, on the east, and the New Red Sandstone of the valley, on the west. This tract is about 16 miles in length, with an average breadth of rather over a mile; and it is divided along its entire length by a fault, which separates the Skiddaw Slates from the higher beds composing the Inlier on the west. The district is very interesting to those who are desirous of tracing the character and relations of the Lake District rocks in their easterly development, after their eclipse by newer formations in the central portion of the Eden Valley. But the main object of the Authors has been to fix the ages of the various formations of the Lower Palæozoic rocks in the Inlier, to determine their organic contents, and to compare them with the corresponding rocks of other areas. Even the Skiddaw rocks are not treated in any detail; and, although there are petrographical notices of certain sedimentary and volcanic rocks in that series, and also of the volcanic rocks of

the Eycott and Rhyolitic groups and of the principal varieties of intrusive rocks, yet the chief interest of the paper, for my present purpose, centres in the beds that lie above the Rhyolitic group.

Succeeding the rhyolite of Knock Pike, which may be regarded as representing the higher portions of the Volcanic Series within the area, are some layers of fine, apparently unfossiliferous ashes, which pass up into calcareous shales with nodular masses of limestone crowded with fossils, some of the calcareous bands being composed exclusively of the valves of *Beyrichia*. One bed of the series having previously been spoken of as the *Discina* (*Trematis*) *corona*-bed, the Authors propose to name the whole the *Corona*-series. This is interesting from the fact that it seems to be older than anything which has been referred to the Coniston Limestone group in the Lake District proper. The fauna is a very marked one, entirely different from that of the ordinary Coniston Limestone, nor has any similar fauna been hitherto recorded from the British Islands. The next beds in ascending order are the Dufton Shales and Keisley Limestone, which are held to be referable to the same subdivision, notwithstanding their lithological dissimilarity. Most of the Dufton Shale fossils are said to be common in the Coniston Limestone, the Bala Limestone, and the *Trinucleus*-shales of Sweden; and the Authors hold that the Dufton Shales, if not actual representatives of the Coniston Limestone, are far more closely allied to it than to the underlying *Corona*-beds with which they have hitherto been associated. The group of fossils in the Keisley Limestone is essentially that of the Coniston Limestone, but there are some curious differences. The *Staurocephalus*-limestone and the Ashgill Shales complete the column of the Coniston Limestone series, and, as we have already seen, are regarded by the Authors as constituting the summit of the Ordovician system. The whole, including the Rhyolitic group, is regarded as of Bala age, the term being used as synonymous with Caradoc, so that the Lower Bala of that district in the sense used by the Authors is not Llandeilo.

Turning our attention now to North Wales, we have lately had a paper on the Llandovery and associated rocks of the neighbourhood of Corwen by Messrs. Lake and Groom. It seems to have been for some time a doubtful point whether true Llandovery rocks are represented in the northern part of Wales; but in 1877 Prof. Hughes concluded that the grit at Corwen is of Llandovery age, and that it forms the base of the Silurian in this area, which includes

a part of the northern slope of the Berwyn Hills stretching along the southern bank of the Dee. The stratigraphy of this slope is worked out with much care. No fossils have as yet been found in the Corwen Grit, but there is a grit at Glyn Ceiriog, occupying a similar position, which has yielded many. The Authors conclude that the Corwen Grit clearly forms the base of the Llandovery in this area, whilst between it and the Tarannon Beds are black shales containing numerous graptolites of the *Monograptus gregarius*-zone. Their researches were still insufficient to show whether Upper Bala rocks are absent or not from the region, though the evidence at Corwen itself seemed distinctly in favour of a break.

Cambrian.—We are now approaching the lower limits of the palæontological column, and there is a corresponding difficulty in the arrangement of the subjects, owing to the existence of beds which some authors regard as Cambrian and others as pre-Cambrian. So long as there are any remains of a fauna to guide us we are on tolerably safe ground, and it thus seems advisable to separate papers which contain references to palæontological evidence from those entirely based on stratigraphy and petrology. Under the description of palæontological evidence one would be disposed to exclude for present purposes most of those enigmatical markings which have been noted, from time to time, in beds presumably underlying the fossiliferous Cambrians. Such beds may ultimately yield to research a distinctive fauna, but at present they must be regarded as mere aspirants to rank in the palæontological column, and are for that reason best placed in the category of 'Fundamental Rocks.' An exception may be made in the case of the Pipe-rock of Assynt, which, although below the lowest recognized Cambrian fauna, must certainly be included with that system, and this also may carry, as hinted by Prof. Sollas, certain rocks in the neighbourhood of Dublin which were once claimed by Prof. Blake as Upper Monian.

The papers dealing with the fossiliferous Cambrian are not numerous. If we exclude those which treat of the Longmynd and the volcanic series from a stratigraphical and petrological point of view, there are not more than half a dozen. North Wales receives notice from Dr. Woodward in his paper on 'Trilobites in the Cambrian green slates of the Penrhyn Quarries.' The papers by Sir J. W. Dawson on the Eozoic and Palæozoic rocks of the Atlantic coast of Canada refer to the whole of the Palæozoic series and include likewise ample notices of the Fundamental Rocks. It

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these correlations, and there is one error of some consequence which Dawson, at the time the papers were written, shared with other Transatlantic authors, viz., in placing the *Olenellus*-fauna above that associated with *Paradoxides*. This mistake was corrected by Brögger, who demonstrated that in Scandinavia the *Olenellus*-zone was at the base of the Cambrian, being succeeded above by the *Paradoxides*-zone; and, according to Dr. Hinde, Mr. Walcott has lately verified this sequence in America.

It would appear from a perusal of Sir J. W. Dawson's first paper that he was there disposed roughly to divide the Cambrian System into three great series, distinguished respectively by *Paradoxides*, *Olenellus*, and *Dikelocephalus*. The former fauna, he remarked, is unknown over the great continental plateau of America, whilst the second, or *Olenellus*-group, slenderly represented on the coast, appears in force immediately within the great Laurentian axis of Newfoundland, being likewise known in the valley of the St. Lawrence by the great masses of limestone full of fragments of *Olenellus*, *Solenopleura*, *Hyolithes*, etc., found in the conglomerates of the Quebec group. Of the upper members of the Cambrian, the *Dikelocephalus*-group, or Potsdam Sandstone, is apparently altogether absent in the Acadian provinces. It seems doubtful if any good equivalent of the Potsdam exists in England or Wales. For a long time this same Potsdam Sandstone was regarded by the geologists of America as constituting the base of the Palæozoic column, since over great areas of Canada and the United States it lies unconformably and directly on the Laurentian. The marginal areas of the Continent have since afforded a great series parallel to the Cambrian of Wales and Scandinavia. In further illustration of this we find at Matane and Cape Rosier true Tremadocs (regarded as a passage-series between Cambrian and Ordovician) filled with *Dictyonema sociale* and containing fragments of characteristic trilobites. Farther inland, on the main American plateau, these beds are not found, but are represented by the peculiar 'Calciferous' formation, a dolomite formed apparently in an inland sea and having a characteristic fauna of its own. The Author then observes that in the sandstone and limestone series of Durness a group of fossils was long ago recognized by Salter as being of this interior-American type, which does not exist either in Wales or on the American coast. He concludes that the trilobitic and graptolitic faunas of the coast mainly belonged to cold northern currents; while the 'Plateau faunas'—richer in cephalopods, gasteropods, and corals

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accumulation, affording time for the fertilization of the sand by the shower of minute pelagic organisms. Truly this was the age of worms, that continued masters of the situation through the period represented by the 'Fucoid'-beds. The 'Serpulite'-grit is evidence of coarser sediment, but after its deposition hardly any material derived from the land entered into the composition of the overlying limestones. Eventually, he continues, nothing seems to have fallen on the sea-floor but the remains of minute organisms, whose calcareous and siliceous skeletons have slowly built up the great mass of limestone and chert so conspicuously developed at Durness. Worms were still in the ascendant, since most of the beds are traversed by worm-casts in such a manner that nearly every particle must have passed through their intestines. Indeed, he considers that the prevalence of these annelid-traces indicates that the limestones cannot be due to coral-reefs. Moreover, only one undoubted specimen of a coral, resembling a *Michelinia*, has been observed. Neither had shell-banks much to do with the accumulation of the limestone, as may be seen from the mode in which the shells occur. The most abundant forms are chambered shells, such as *Nautilus*, *Lituites*, and genera of the Orthoceratidæ. Next in order are the gasteropods, chiefly *Maclurea* (heteropod), and *Pleurotomaria*, whilst the lamellibranchs and brachiopods rank last in point of numbers. Sponges of the genera *Archæocyathus* and *Calathium* occur at intervals in the muddy matrix. However, the larger masses of chert in the limestone do not seem to be derived from sponges, but more probably from the siliceous skeletons of diatoms. No undoubted remains of foraminifera have been discovered, and he thinks it unlikely that minute organisms would be preserved, owing to the fact that the limestones are crystalline and that many of them are more or less 'dolomitized.' This latter word is the only one to which I would take exception. If we substitute 'dolomitic,' it will leave open the question of origin, which I think may be important in this case.

Mr. Peach endorses the views of Salter that the fossils are of an American type. So far as the order of succession of the beds is concerned, we have, he says, an almost exact counterpart of the strata exposed along the axis of older Palæozoic rocks, stretching from Canada through the Eastern States of the Union. His inferential correlation of the 'Pipe-rock' of Sutherland with the Potsdam Sandstone, based on the prevalence of *Scolithus*, will scarcely hold good in view of the later researches of the Survey. The correlation of the Durness Limestone with the 'Calciferous

Group' is probably nearer the mark. The subsequent discovery of the *Olenellus*-zone in the 'Fucoid'-beds may perhaps induce Mr. Peach to regard the Durness fauna as probably an Upper Cambrian one.

We should now seek for a parallel to the Durness Limestone in other parts of Scotland, outside the area technically known as the North-west Highlands. This may be found, according to Sir Archibald Geikie, in the Altered Limestone of Strath in Skye, which had been regarded by great authorities as an instance of contact-metamorphism in a rock of Liassic age. Many years ago the Author expressed a suspicion that this rock might turn out to be of the age of the Durness Limestone, and recent investigation has convinced him that such is the case. In lithological characters the rock differs from the Lias of the district, consisting in its lower part of dark limestones full of black cherts, and comprising a higher group of white limestone with little or no chert. Moreover, white quartzite is found in association with the limestone at several places in Strath; also representatives of the well-known 'Fucoid'-beds at Ord in Sleat. These latter strata form a persistent band which may be traced from Sutherland into Skye. The palæontological evidence is also favourable. It would seem that the Lias rests upon this Cambrian limestone unconformably, and actually contains at its base a coarse breccia largely composed of pieces of the older limestone along with fragments of chert and quartzite. The most singular thing is that the metamorphism is stated to be confined to the Cambrian limestone and to have been produced by large bosses of granophyre (syenite) of Tertiary age. Mr. Marr considered that the recognition of the Durness Limestone in Skye might be expected, and referred to the Stinchar Limestone of the Girvan district as being of the same age, viz., that of the *Orthoceras*-limestone of Sweden.

A further advance has been made in the survey of the Cambrian area of the North-west Highlands by the discovery of *Olenellus* in the 'Fucoid'-beds and 'Serpulite'-grit of the Dundonnell Forest in Ross-shire. Particulars are given by Messrs. Peach and Horne in a recent communication to the Society, wherein they comment upon the remarkable persistence of the sub-zones already identified in Assynt and at Loch Eriboll. The basal quartzites are, for the most part, destitute of those worm-casts so characteristic of the overlying zone, but in the Ben Eay forest, south of Loch Maree, certain dark grey shales, which may probably yield organic remains at some future time, occur near the base of the series. The five sub-zones in the

overlying 'Pipe-rock,' based on the peculiar features of the vertical burrows in the quartzite, are also found to hold good, having been traced even south of Loch Maree. In the third sub-zone *Salterella* has been noted on Ben Arkle (Sutherland) in a massive quartzite free from vertical worm-burrows, and a similar band without the 'serpulite' has been noticed in the Loch Maree district.

We now come to the details of the discovery of *Olenellus*. The 'Fucoid'-beds, it would seem, preserve their character as brown dolomitic shales with bands of rusty dolomite; and it is in the upper portion of this series that fragments of this early trilobite were first found. A mountain-stream has cut a natural section, and the attention of the observer, we are told, is at once arrested by two prominent bands of dark blue shale, intercalated in the normal dolomitic beds of the zone. The upper band is about 3 feet and the lower one about 9 feet from the top of the 'Fucoid'-beds, and it was in the lower band that the fragments were found, the best specimens being confined to a seam less than an inch thick. It would also appear that dark blue shales, near the top of the 'Fucoid'-beds, have been observed in various localities, evidently occupying the same horizon as the *Olenellus*-shales in the Dundonnell Forest. The Authors were sanguine at the time that these shales would be traced continuously through a great part of Ross-shire. The locality where the trilobites were found in the zone of the 'Serpulite'-grit is about 8 miles N.N.E. of Loch Maree. At this spot a small escarpment gives a full section of the zone, here about 36 feet thick, consisting of quartzite and quartzose grits with a little shaly matter here and there, especially in the lower half. In a band of dark blue shale in the lower part of this formation a head-shield and other fragments of *Olenellus* were found, the species being apparently the same (*O. Lapworthi*) as that occurring in the 'Fucoid'-beds.

Of the organic remains obtained from the dark shale-bands fragments of trilobites are the most abundant, but with these are associated the remains of pteropods, among which a *Salterella* like *S. pulchella* occurs. Several species of *Hyolithus* also are found, besides one specimen of a large entomostracan. The association of *Salterella* with *Olenellus*, say Messrs. Peach and Horne, induces a hope that traces of this trilobite may be found wherever the 'Serpulite' has been shown to abound, possibly even in the lowest group of limestone. After these discoveries it could no longer be doubted that the Quartzite, 'Fucoid'-beds, and 'Serpulite'-grit belong to a very

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illustration of the physical relations of the strata cannot fail to call to our minds some of the efforts of previous authors, who, without the key, were vainly endeavouring to explain on ordinary stratigraphical principles the remarkable phenomena along the line of chief disturbance. It is claimed for Prof. Lapworth, and perhaps not unjustly, that he, working with tools forged by himself, has given the key to the geology of two great provinces of Scotland.[1] At least in this district we may allow that he materially assisted in opening the eyes of the officers of the Survey and others to the possibilities of the case, and that the former have not been slow to profit by his teaching. Nine years have now elapsed since the close of the Highland Controversy, and the interval has been one of steady progress in recognizing the true, but nevertheless extraordinary, structure of the country. Well indeed might Prof. Lapworth comment on the descriptive character of this portion of Messrs. Peach and Horne's paper, whilst allowing that the general conclusions arrived at were very similar to those which he had himself indicated. Such sections are, to a certain extent, astounding, yet they do occur.

The subject of Thrust-planes has been pretty well grasped by this time, and some people have been looking for them where probably they do not exist. The three chief thrust-planes of this region in order from west to east are—(1) the Glencoul Thrust; (2) the Ben More Thrust; (3) the Moine Thrust. A series of horizontal sections drawn across the general strike of the district exhibits the effects of one or more of these in combination with the results of minor thrusts. Nothing but the most intimate acquaintance with each particular rock could ever have enabled the authors to put together the pieces of such an extraordinary jumble, though when once the idea is grasped there seems to be a certain amount of system in the displacements. One of the more northern sections, about five miles in length, exhibits the wonderful manner in which a swirl of the Cambrian beds, from quartzite to dolomite all told, is caught up, as a kind of inlay, into the flanks of the Archæan gneiss. It was the re-appearance of this Archæan gneiss, far to the eastward of its accepted position, which so puzzled the older geologists, often figuring as the 'igneous rock' of Murchison or the 'Logan rock' of Heddle. Such, within certain limits, is the structure of Coniveall, the southern peak of Ben More of Assynt. This structure, at the Stack of Glencoul, is further complicated by an outlier of the eastern or Moine Schists, brought forward several miles to the westward of

[1] Bertrand, *op. cit.* p. 121.

their original position by the effect of the Moine thrust-plane—that most terrible of all deceivers. The horizontal section from the Knockan Cliffs to the Cromalt Hills is another edition of the same story. It is needless to say that such classical sections as Cnoc an drein, Coniveall, Ben More, and Breabag, with all that wonderful slicing and plication which each exhibits more or less, are dealt with in a fashion that leaves no doubt, when once the key has been obtained, as to the true structure of those remarkable localities. The section across Ben More shows at a glance what a large proportion of this mountain-range consists of Archæan gneiss with its characteristic basic dykes. To use, with a slight modification, the words of the Authors, the slice of Archæan rocks, bearing the thin capping of Torridon Sandstone and Cambrian strata which constitute the actual summit, is of large dimensions. Here the Archæan gneiss with its basic dykes is exhibited in a grand cliff about 1500 feet high overlooking Dubh Loch More, whence it sweeps across the lofty peaks separating the Oykel from the Gorm Lochs. Though still recognizable as a part of the old Archæan platform, the rocks are stated to have undergone important changes due to the movements which have affected them. It was these changes which formerly prevented geologists, Nicol in most instances excepted, from recognizing an old friend under such altered circumstances.

We must now proceed to consider the nature of the metamorphism resulting from these post-Cambrian movements. The Authors observe that with each successive maximum thrust there is a progressive alteration in the displaced materials. For instance, the great slice of Archæan rocks brought forward by the Glencoul Thrust does not present any striking evidence of deformation, except close to the lines of disruption. The alteration of the Archæan rocks is more pronounced above the horizon of the Ben More Thrust in Assynt, but it is in the belt of sheared gneiss and green schist underlying the Moine thrust-plane that we have the most remarkable evidence relating to this kind of metamorphism.

In the basal conglomerate, or 'Button-stone,' of the Torridon Sandstone the softer pebbles of gneiss and the fragments of the basic Archæan dykes have been crushed, flattened, and elongated in the direction of movement. Indeed, in some cases, they have been drawn out to such an extent as to form thin lenticular bands of micaceous or hornblende-schist flowing round the harder pebbles of quartz-rock. The original gritty matrix has been converted into a

fine, micaceous, chloritic schist showing exquisite 'flow-structure,' winding round the elongated pebbles in wavy lines—in fact the matrix has been converted into a fine crystalline schist. In the grits, etc., of this formation cleavage-planes have been developed, dipping in a direction opposite to that of the original bedding, and more or less parallel with the plane of the maximum thrust. As the materials differ in their powers of resistance the planes of schistosity, in some cases, form a series of sigmoidal curves. Lenticular veins of pegmatite occur more or less parallel with the new schistose planes, whilst sericite is found to be abundant in the finer bands.

The various members of the Cambrian series underlying the Glencoul thrust-plane show little alteration, even when they have been piled on each other by minor and major thrusts, but above the Ben More thrust-plane a greater amount of alteration takes place, the steps in which may be traced until such a bed as the 'Serpulite-grit' becomes a quartz-schist in which 'serpulites' are no longer visible: meanwhile the limestone becomes crystalline. As regards the post-Cambrian metamorphism of the intrusive igneous rocks, there is a certain progressive change from west to east. Thus, sheets of felsite injected along the bedding-planes of the basal quartzites have been converted into soft sericite-schists; and in another place a felsite-dyke on the same horizon has had cleavage developed parallel to the plane of the principal thrust, whilst but little alteration is noticed in the quartzite itself. Where the alteration is extensive, as in the neighbourhood of the Moine thrust-plane, the various igneous bands lose their distinctive characters: the fine-grained diorites in the limestones are represented by green hornblende-schists and chlorite-schists; the holocrystalline rocks with porphyritic felspars appear as bands of 'augen-gneiss' and 'augen-schist'; and finally, along a line of powerful thrust in the great granitoid sheet east of Loch Borolan, there is a belt of 'augen-gneiss' with pyroxenes, which, existing originally as porphyritic crystals, now appear as 'eyes' in the foliated rock.

As rightly pointed out by Messrs. Peach and Horne, there is much valuable information to be gathered from a study of this progressive metamorphism. Amongst other inductions it is obvious that the crystalline rocks, where they occur in thin sheets, become schistose more readily than the ordinary clastic rocks. As might be expected, too, the Torridonian sandstones and shales are more easily cleaved than the Cambrian quartzites. In fact, when we bear in mind

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very fully treated from this Chair, it is not my purpose to deal with pre-Cambrian volcanic rocks on the present occasion, except in part as to their possible relations with the sedimentary series.

When we bear in mind that the pre-Cambrian volcanic series is of considerable importance, its elimination materially diminishes the amount of matter which has to be dealt with. Practically we are limited to the sedimentary series and to a portion of the crystalline schists. There have, of course, during the past seven years been a very great number of papers of a more or less petrological nature, where the rocks described may or may not belong to the Fundamental group. The following authors, however, have written papers on rock-groups whose position below the fossiliferous Cambrian cannot be doubted. These are Messrs. Peach and Horne, Blake, Callaway, and Rutley, and Miss Raisin. The bulk of this literature relates to Wales and Anglesey, but Shropshire and the Malverns come in for a fair share.

Oddly enough, the best defined pre-Cambrian, or Fundamental sedimentary series, is to be found in the North-west Highlands, a district which only a few years ago was an enigma, but which we hope may now supply a clue to regions apparently more obscure. At length geologists have discovered a pre-Cambrian system which has a well-defined base and an equally distinct summit. It may be said that this is no discovery, after all, since the Torridon Sandstone has attracted attention ever since the days of Nicol and Murchison. But we owe to Messrs. Peach and Horne, in the first place, the clearest proofs that the Torridon Sandstone is unconformable to the overlying system, a fact which was disputed in the 'Quarterly Journal' not very many years ago. Secondly, the same authors having demonstrated on palæontological grounds the Lower Cambrian age of the overlying series, it follows that the Torridon Sandstone, though entirely sedimentary and unmetamorphosed, is of pre-Cambrian age, and there seems no reason why it should not prove to be fossiliferous. Indeed, hopes have been expressed that a fauna might be discovered, but as yet I have not heard of these hopes having been realized.

It would appear that there is a considerable amount of variety, within the area, in the formation known as the Torridon Sandstone. As far as I myself remember it, the grits partake very much of the nature of an arkose, showing that the felspar-fragments had not suffered extremely from kaolinization, and thus pointing to rapid accumulation. Much of the material appears to have been derived from rocks similar to the underlying Lewisian gneiss. In the far North-

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Needles of Howth, in pinkish-coloured beds of sandstone, innumerable small worm-tubes, about $\frac{1}{8}$ inch in diameter, occur running transversely to the planes of bedding, and these seem equally to recall the 'small pipes' which occur on the lowest annelid-horizon of Sutherland. We must not forget, however, that worm-casts have been noticed in the upper beds of the Torridon Sandstone.

Crossing St. George's Channel, we find ourselves in Anglesey, a land of pre-Cambrian mysteries, which I scarce venture even to glance upon. The older rocks of the island have been described with the most careful detail by Prof. Blake in his comprehensive paper on the Monian System; but since that author's conclusions have already been discussed in a previous Presidential Address, it would seem like a work of supererogation to dwell on this topic at any length on the present occasion. It will be remembered Prof. Blake desired to show that the whole of the rocks which, under various names, had been described as pre-Cambrian constitute a single well-characterized system, of which the various divisions hitherto described are integral and inseparable parts. These rocks are found in six districts of Anglesey. The Lower Monian is represented by grey gneiss and mica-schists, quartzites, chloritoid and chloritic schists; the Middle Monian is represented by a volcanic facies and by a slaty facies. The South Stack series also belongs here, but in the map showing the distribution of the Monian rocks in Anglesey no part is assigned to the Upper Monian, although it would appear that the Howth Hill and Bray Head rocks, previously mentioned, are regarded as possibly Upper Monian. Of course it is well known that the authors and originators of the other pre-Cambrian systems do not look with favour upon the Monian system, which, like Aaron's rod, seemed likely to swallow up the rods of the other magicians. Into this controversy I must not enter, the more so as it would involve the consideration of points already discussed by Sir Archibald Geikie. It is enough to indicate that the Director-General of the Geological Survey has still more recently given his opinion that the coarse gneisses of Anglesey present some striking external or scenic resemblance to portions of the Lewisian rocks, whilst the schists, quartzites, and limestones of that island present a close resemblance to the Dalradian of Scotland and Ireland; the quartzites, like those of the Highlands, containing worm-burrows.[1] Dr. Hicks still more recently quotes these opinions as practically endorsing his own views: names apart, where Sir Archibald sees Dalradian, he mainly

[1] 'Journal of Geology,' vol. i. pp. 12, 13.

sees Arvonian—that is all the difference[1]; whilst Prof. Blake, writing in 1890, stated that, at that time, none of the pre-Cambrian or Monian rocks of Anglesey had been definitely identified with rocks elsewhere.[2]

The Monian controversy now transfers itself to Shropshire. Prof. Blake, it would seem, had suggested that the Longmynd rocks were referable to the Upper Monian. Writing in the spring of 1890, he finds that they are divisible into two groups, of which the lower only can be thus referred. The upper of these two groups, according to Prof. Blake, represents the true Cambrian, and the junction between the two groups is unconformable. Moreover, the volcanic rocks on the east, associated with Caer Caradoc, are not Middle Monian as formerly supposed by him, but represent the interval between Monian and Cambrian, or, in other words, they are above the lower Longmynd group, and may possibly be on the horizon of the Bangor series, which for him is part of the unfossiliferous Cambrian. It is alleged that this position is supported by detailed stratigraphy. On the other hand, there followed a rejoinder from Dr. Callaway in his paper 'On the Unconformity between the Rock-systems underlying the Cambrian Quartzite in Shropshire.'

This paper resolves itself into a series of negations as to Blake's position. Thus, the felsites regarded by himself as Archæan have not been shown to be intrusive in the Longmynd rocks; neither has it been proved that the Longmynd series is divisible into two groups separated by an unconformity. Also, the conglomerates and grits associated with the Uriconian (Caer Caradoc series) are an integral part of that system, and are not of Cambrian age; neither are the granitic rocks of Shropshire intrusive in the Uriconian. As regards the relations between the Uriconian and Longmyndian, he allowed that it was premature at that date (January 1891) to assign a pre-Cambrian age to the Longmyndian, but he was disposed to favour the idea of a break between it and the Uriconian, which was essentially a volcanic formation, whilst the Longmyndians were characterized by their even sedimentation. He thought that such a change of conditions must indicate a break in time, though the unconformity need not necessarily be very great. He also took the opportunity of pointing out that the occurrence of Malvernian granites and schists in the Uriconian conglomerates indicates the existence of an unconformity between the holocrystalline and the

[1] Geol. Mag. 1893, p. 396.
[2] *Ibid.* 1890, pp. 313, 314.

volcanic series. On this occasion, although Blake continued to maintain his unconformable overlap, he does not appear to have had any supporter. Dr. Hicks even went so far as to assert that the Caer Caradoc volcanic group had constituted a source of supply for the Longmynd series, in which there were no indications of volcanic rocks. At that time he saw no reason for separating the Longmynds from the Cambrian. It may be that he has modified his opinion, since it has been shown that the Cowley Sandstone, which is the associate of the quartzite, contains the oldest-known Cambrian fauna, and must therefore be very near the base. This would seem to leave but little room in the Cambrian system for the Longmynd rocks, which may be regarded for the present as occupying a high position in the Fundamental Rocks, somewhat analogous to those of Howth and Bray Head, though not of necessity occupying precisely the same horizon.

Once more we find Prof. Blake busy with the unfossiliferous sedimentary series, and this time with the rocks mapped as Cambrian in Caernarvonshire. In his first contribution to this very thorny subject, written some years ago, the Author alludes to the triangular duel which had for some time been going on between Messrs. Hicks and Hughes, as representing the most uncompromising pre-Cambrianism, of the one part, Prof. Bonney of the second part, and the officers of the Survey, as defenders of Ramsay, of the third part. Not that Prof. Hughes and Dr. Hicks have been at all times agreed in their respective interpretations of this troublesome district, nor that the officers of the Survey have undertaken to maintain the views of Sir Andrew Ramsay in their entirety. The Author tells us that he was led to study the area from its relations to the rocks of Anglesey, with the result that the evidence on the ground is not sufficient to justify the conclusion that pre-Cambrian rocks can be said to occur, although, in his map, the igneous mass between Caernarvon and Bangor is represented as pre-Cambrian of two distinct types. In his opinion the views of the Survey, except as regards metamorphism, most nearly approximated to the natural interpretation of the facts that were known at the time, although new facts now necessitate a modification.

He altogether disputed the notion of a basal Cambrian conglomerate in North Wales, alleging that in the Bangor and Caernarvon area three different conglomerates had been confounded. He further alleged that the only conglomerate in the district which showed distinct unconformity upon the underlying rock was of Arenig age.

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The general succession is argued to be the same in the isolated portion south-east of Bangor, as in the main mass. Not having been able to make things fit in with the existing Survey map, he offers one of his own, which he does not bring forward as absolutely correct; doubts may affect the surface-distribution, but of the vertical succession, he claims, there can be no doubt whatever. The presence of the summit-beds of Blake's Cambrian would seem to depend on whether the Bronllwyd Grit, which he regards as belonging to the overlying group, rests conformably or unconformably on the underlying rocks. Amongst his conclusions he regarded it as proved that the rocks to the west of the felsite belong to the lower part of the series, and those to the east to the upper, both being determined in areas where the felsite is absent, and hence it appears probable that the felsite mass is a volcanic complex belonging to the middle of the Cambrian period.

In his last paper 'On the Felsites and Conglomerates between Bethesda and Llanllyfni,' Prof. Blake, in support of his previous argument, asserts that the felsites occur on so many horizons that they could only be one mass if they were intrusive. He regards it as having been abundantly shown that the conglomerates, derived from these felsites—at all events on the east side of the faulted Silurian strip—do not lie at the base of the Cambrian series. He allows, however, that it is another thing to demonstrate that any of them are of later age than the workable slates—and to this he now limits himself. Such a contention cannot be demonstrated off-hand; the proofs as to the relations of the conglomerates to the felsites require, he says, a careful consideration of the whole obtainable evidence, and this is so interwoven that it is necessary to take the localities in geographical order and exhaust the evidence in each. Of course we cannot follow Prof. Blake, on the present occasion, across country generally, but his reading of the Moel Tryfaen section presents features of considerable novelty. He evidently expects that this will give the *coup de grâce* to the idea of pre-Cambrians occurring in this district. It is clear that previous observers have been hasty in assuming that the great crags of conglomerate on the summit are really represented in the interior of that mountain. For the first time we have something like a section as afforded by the adit: the length is a little over a quarter of a mile; the average dip of the beds about 60°. The Author shows that, next the Purple Slates, there is a conglomerate of quartz-pebbles in a gritty green matrix, say 4 feet thick, and that all the rest consists

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ground, such as might yield a fauna. Hence there is little to be hoped from the possible discovery of fossils. So long, therefore, as the matter has to be decided by stratigraphy, aided sometimes by lithological considerations, the fight is apt to be prolonged.

Now, as regards the latter method, Prof. Bonney, we are told, has often insisted on the slight degree of difference between some of the later Pebidian and the earlier Cambrian rocks. This is the view that I have myself always maintained with regard to the beds in South Wales. Consequently, where palæontology, as at present, gives us no clue and where lithological distinctions fail, if we wish to draw a line at all we are bound to fall back on stratigraphy. It rests, then, with those who are desirous of establishing the existence of pre-Cambrian rocks in North-west Caernarvonshire to draw that line. Do they still believe in the existence of a basal Cambrian conglomerate along the eastern margin of the great felsite mass which terminates at Llanllyfni? Prof. Blake alleges that conglomerates and felsites are apt to wait upon each other without special reference to period, while Dr. Hicks but lately spoke of a pre-Cambrian ridge in the neighbourhood of the Penrhyn slate-quarries, on both sides of which the Cambrian succession is shown, the basal Cambrian conglomerate being traceable on an irregular pre-Cambrian floor. At this stage the controversy rests for the present. If an impartial jury were empannelled and the evidence now available placed before them, it is probable that they would take refuge from their perplexity in a verdict of 'Not Proven' to each of the various contentions.

To this subdivision of the Fundamental Rocks also belongs Prof. Lloyd Morgan's paper on the Pebidian volcanic series of St. David's, which, for reasons already mentioned, I am precluded from noticing on the present occasion. The clastic rocks of Charnwood Forest, too, as decided in their recent paper by Messrs. Hill and Bonney, are likewise referred to the latest epoch in the pre-Cambrian series—the Pebidian.

The Crystalline Schists, etc.—The term Archæan is by some restricted to the lower subdivision of the Fundamental Rocks. Be this as it may, the Crystalline Schists and Gneisses are sufficiently distinct from the rocks of the upper subdivision to be considered under a separate section. Again, then, we seem bound to turn to Messrs. Peach and Horne's exhaustive memoir for an account not only of the original types of Lewisian Gneiss, but also of the subsequent changes which these have undergone. This subject has,

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and 'syenitic' rocks of medium and fine texture. The central block of the range, from the Wych to the fault in Swinyard's Hill, consists chiefly of the lower and upper middle series, but with a portion of the lower series at the south end. The upper series consists of mica-schist and finely crystalline gneiss. He had little doubt that the fine-grained schists were sedimentary, as they even contained beds of quartzite. He further discusses how far the foliation of these rocks and their main divisional planes represent original stratification, leaving this point an open question. He observes that, in the Malverns, the strike of foliation is not parallel to the axis of elevation. Although Mr. Rutley was inclined to believe that the divisional planes may be planes of original stratification, he cannot say more than that they are original planes of some sort, between which the rocks exhibit diverse lithological characters.

In the second portion of his paper this Author gave the results of the microscopic examination of these rocks, which tended to show that those of a truly eruptive origin are more plentiful in the range than he at first supposed. He admitted there was no reason to believe that the alteration of any ordinary sedimentary rocks could have resulted in such a vast amount of hornblende as is found in these gneisses, and he suggested a pyroclastic origin for some of the beds. It is evident that he could not free himself from the idea that some at least of the structural planes in these rocks indicate planes of stratification; and that the foliation, in many cases if not in all, denotes lamination due to deposition, either in water or on land-surfaces, possibly accentuated by subsequent movements. We plainly perceive that Mr. Rutley, at that time, regarded the main mass as consisting of ordinary sediments metamorphosed into schists and intruded upon after their formation by igneous masses. Although he could not exactly make out the relations of foliation to sedimentation, he felt sure that there had been deposition of some sort. Nor has he very much altered that position in more recent years. Speaking, for instance, when Dr. Callaway's second paper was read, he allowed that a certain number of rocks were eruptive, although he considered that a large portion consisted of the detritus of eruptive rocks, while towards the south they were mainly micaceous schists and bedded quartzites, which he regarded as altered sedimentaries. When Dr. Callaway's third paper was read, Mr. Rutley went so far as to allow that the schists of the Malvern Hills had been formed, to some extent, from plutonic rocks. This we must

regard as a concession to modern opinion with reference to the origin of many gneissic rocks, not only in the Malverns, but elsewhere.

Turning now to the consideration of Dr. Callaway's triple memoir on the Malvern Hills, we find that his first paper offers the results of a preliminary enquiry into the genesis of the crystalline schists. Dr. Callaway expressed his belief that many of the Malvern schists had been formed out of igneous rocks, but he limited his observations, in the present instance, to certain varieties, such as diorite, granite, and felsite. The products of metamorphism were divided into two groups. *Simple schists* are those derived from the alteration of one kind of rock—thus, hornblende-gneiss from diorite; mica-gneiss from granite; and mica-schist from felsite, which latter rock is seen gradually to acquire a parallel structure. Accompanying this mechanical alteration in the felsite is a mineral change; mica at first appears in very small quantity, either filling cracks or accentuating the parallelism; in a more advanced stage the mica lies in imperfect folia, and sometimes forms a partial coating to grains of quartz; finally there is little left but quartz and mica, the latter in folia and enveloping individual quartz-granules. *Injection-schists* are those formed by the intrusion of veins which had acquired parallelism by pressure; this group being afterwards subdivided into *Schists of primary injection*, in which one rock was injected by another, and *Schists of secondary injection*, formed by the infiltration of secondary minerals along shear-planes. It was further noted that, in the majority of cases, particular varieties of schist occurred in the vicinity of the igneous masses to which they were most nearly related in mineral composition; and that the mineral banding of rocks in the field was more like vein-structure than stratification. The metamorphism, he states, had been brought about by lateral pressure, evidence of which was to be seen in the intense contortion of granite-veins and in the effects of crushing as observed under the microscope.

The conclusions to which the Author pointed in this paper were, on the whole, well received; and it may be said that the belief has continued to gain ground that the Malvern rocks are mainly igneous rocks rendered gneissoid from pressure. There may be a few exceptions, such as the rocks described as quartzite, and certain fine-grained schists not obviously in connexion with igneous masses. It is by no means clear, however, that the views so ingeniously put forward in his two latest papers by Dr. Callaway will meet with

such general acceptance. These papers are too exclusively mineralogical to be noticed at any length on the present occasion, relating, as they do, principally to the production of secondary minerals at shear-zones, and discussing difficult problems in connexion with change of substance on a large scale in rock-masses (metasomatosis). The chief chemical and mineral changes, he says, have taken place in bands of rock which have been subjected to a shearing movement, so that the metamorphism may be described as 'zonal.' The maximum of alteration has been produced in diorite where it has been sheared in proximity to granite-veins. It is considered that contact effects are here combined with dynamic metamorphism. Amongst the most important chemical changes are the removal of bases and the combination of potash with some of the constituents of diorite. The chief mineral changes are stated to be the reconstruction of felspar, and the production of biotite through chlorite from hornblende; of white mica from orthoclase, plagioclase, black mica, and chlorite; also of granular quartz, sphene, and actinolite. Dr. Callaway is likewise prepared to go a long way in the direction of wholesale substitution. The appearance of sedimentary rocks towards the south end of the chain, so often urged by Mr. Rutley, is quite delusive; all this is the result of more intense shearing. The more highly quartzose the rock, the more intense has been the metamorphism. Even a diorite may have all the bases squeezed or dissolved out of it, and thus figure in the end as an acidic schist. The gradual elimination of the magnesia, a necessary accompaniment of this operation, is one of the points to which attention is drawn in the last paper. It would have been more to the purpose if the Author could have shown us how to get rid of the alumina.

Reverting to the main question, I am not aware that there is any good field-evidence as to the existence of shear-zones at all in this region, though mere shear-planes, where the parallelism is more or less accidental, are stated by Dr. Irving to be conspicuous structural features of the rock-masses exposed to view in extensive quarries at North Malvern and elsewhere.[1] It has been hinted that the crushed material in the so-called shear-zone at West Malvern may perhaps be a 'friction breccia,' and the possibility of other supposed zones being mere dislocations has also been indicated. Altogether we must admit that Dr. Callaway, by his three papers in the Quarterly Journal, has made a material contribution to our knowledge of the origin of the Malvern crystallines, besides having raised

[1] Geol. Mag. 1892, p. 461.

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the Propylites of the Western Isles, relate to matters which have been more or less touched upon by Sir A. Geikie in his second Presidential Address, and consequently I need not bring them prominently forward on the present occasion. The second of these papers was mainly written for the purpose of showing that the 'felstones,' described by the Author in his first paper as constituting the oldest series of the Tertiary volcanic rocks of the Western Isles, belong to that variety of the andesites known as propylites. These rocks, when found in an unaltered state, present remarkable analogies with the andesites of Iceland and the Faroe Islands, whilst in the altered condition in which they usually occur the propylites of Scotland resemble those of Eastern Europe and other regions. A detailed description ensues, and the Author states that these rocks exhibit every gradation in minute structure from holocrystalline forms (diorites) through various 'granophyric' types into true vitreous rocks such as pitchstones; whilst, by carefully following in the field the much-altered rocks to points where they retain some of their original characters, the propylites can be shown to represent various interesting types of andesite and diorite. The chief agent in producing change in these rocks he considers to have been solfataric action, and this was shown to have accompanied the intrusion into the andesites of masses of igneous material, acid in composition, such as granites and felsites.

Forming a very striking contrast with the older Tertiary andesites (propylites) are the numerous scattered and generally small masses of rock, which belong to a late epoch in the Tertiary volcanic period, and constitute the youngest eruptive rocks of the British Isles. One interesting example is afforded by the Scuir of Eigg. These rocks have the mineralogical constitution of the augite-andesites, but differ from the older series in the relative proportion of crystalline and glassy constituents. Thus, holocrystalline aggregates of basic composition are found passing, as the quantity of acid glass increases, through various phases until they finally assume the vitrophyric form of pitchstone-porphyries. The rocks of the Tertiary dykes in the South of Scotland and the North of England were shown to agree with these later Tertiary andesites, both in their mineralogical constitution and in the peculiar phases which they exhibit.

In his paper on Composite Dykes in Arran, read at the close of last session, Prof. Judd has further supplied us with valuable information on this very subject, the analogues of the Arran dykes

being, as he observes, found likewise over an area extending from Yorkshire on the east to Donegal on the west. He does not hesitate to apply the term 'volcanic' to a series of infilled fissures, whose subaerial products have been so insignificant that conspicuous traces of them are only known to exist at a few points, such as Ben Hiant in Ardnamurchan and the Scuir of Eigg. The chief types of these late ejections are represented by a series of rocks, such as the Cleveland dyke and similar eruptive masses, ranging from augite-andesites to dolerites; in these there is not much glass, as a rule, but occasionally this may be present in such quantity as to produce a pitchstone-porphyry. The other type of rock is represented by the various 'pitchstones' of the Western Isles of Scotland. These rocks are of much more acid composition than the before-mentioned augite-andesites, and their silica-percentage ranges from 65 to 75, the vitreous groundmass being usually in excess; by devitrification they pass into various forms of felsite and quartz-felsite.

In the study of these dykes Prof. Judd considers that there is abundant evidence of the process of differentiation of lavas. Those of Arran are especially instructive, as affording proofs of the re-opening of the fissure after its first injection and the introduction of materials of a totally different composition. Hence the differentiation in these cases must have taken place previously. One of the most interesting examples of the union of the two types of late Tertiary lavas, viz. the basic augite-andesite and the acid pitchstone, in a single dyke, occurs in the great mass of Tertiary granite occupying the northern half of the Island of Arran. This is known as the Cir Mhor dyke, which has a felsite-and-pitchstone centre, whilst the sides are composed of a porphyritic augite-andesite, the acid and basic rocks being always completely distinct, though varying in relative width. They are also strongly contrasted with each other, alike in the characters of all their porphyritic crystals and of their vitreous bases. The acid rocks, however, contain a few crystals evidently derived from the basic rock, which in this case must have been the first to come up. The microscopical characters of the rocks composing the Cir Mhor dyke are described with considerable detail, and mention is also made of hyalite as a constituent of the acid portion of the dyke.

On the shore and in the cliffs at Tormore, on the west coast of Arran, there occurs a remarkable plexus of dykes, many of which, according to Prof. Judd, supply striking illustrations of that class

of composite dyke where the fissure has been reopened. In some cases, he says, the acid rock was clearly introduced after the basic, in others the order of ejection of the two materials was reversed. In some instances the line of weakness, along which the opening and re-injection of the dyke took place, lies towards the centre, at other times it is at the side of the dyke, and occasionally it traverses the dyke-mass in a sinuous manner. He consequently claims that the interval between the first and second injection of these dykes must have been sufficiently long to allow of the complete consolidation of the older rock. As regards the respective ages of the acid and basic rocks in these dykes, if position has anything to do with it, I would point out that, out of five diagrammatic plans of these dykes or of portions of them, in every case, whether the containing rock be granite or sandstone, the augite-andesite or basic material is represented as lining the sides, whilst a centre of varying width is occupied by quartz-felsite, pitchstone-porphyry, pitchstone, dacite, or some such rock.

In his summary, it will be observed that the Author especially guards against any suggestion as to the accidental association of the augite-andesite and 'pitchstone' in these composite dykes of Arran. All the facts, he says, point to the conclusion that the fissures were injected from the same subterranean reservoir, but that this reservoir contained two magmas of totally different chemical composition. Rejecting in the case of the dykes of Arran the idea of selective crystallization and liquation in the already injected material, he says that we are compelled to fall back upon the view that an actual separation takes place amongst the materials of a molten magma before the work of crystallization has commenced. How this may have been effected has exercised the minds of experimentalists and others for a long period of time.

Before quitting this part of Scotland I must draw your attention, though very briefly, to another matter in connexion with these Tertiary volcanic rocks. Prof. Judd, who had the good fortune to make some of the most remarkable discoveries in the Western Isles of Scotland which have been placed to the score of a British geologist, has long been at issue, as you all well know, with an equally distinguished authority as to the order of appearance of certain Tertiary eruptives. Quite lately, in speaking of the five great centres of volcanic outburst in the West of Scotland, Prof. Judd again affirmed the sequence in time of the three kinds of igneous material to have been, firstly the rocks of intermediate

as that where the inclusions are said to be found. At this place he had on a former occasion described the occurrence of numerous veins proceeding from the mass of granite there and traversing the gabbro, and if these observations were correct they afforded a complete demonstration that Prof. Judd had reversed the order of appearance of the two rocks; moreover, he considered that his own view of the case received corroboration at many other localities in the Western Isles. With reference to the case mentioned by Sir A. Geikie in the Cuillin Hills, Prof. Judd alleged that earlier writers had failed to discover any veins proceeding from the granite into the gabbro, whilst he had himself searched for such evidence without being able to find anything of the kind. It is fortunate that we are not on the present occasion called upon to decide on the merits of this case, which, in its narrower issues, resolves itself very much into a matter of field-geology. The general question as to whether the great acid eruptions of the Hebrides preceded or succeeded the basic ones is probably too large to be decided by the evidence of a single locality. Indeed, when we have to deal, not with one, but with a multiplicity of volcanic complexes, it is just possible that one section may tell a story which another section contradicts.

Once more the venue shifts to the North-west Highlands—to the mainland of Sutherland and Ross—and we are again led to consult Messrs. Peach and Horne as to the igneous rocks in the Torridon and Cambrian formations. These occur as intrusive masses on several horizons. The famous Loch Borolan porphyry finds a place here, and this rock may be further studied in a recent contribution to the Transactions of the Royal Society of Edinburgh[1] by Messrs. Horne and Teall, where those authors describe 'Borolanite' as an igneous rock intrusive in the Cambrian Limestone of Assynt and the Torridon Sandstone of Western Ross. The proofs of the intrusive nature of these masses are said to be conclusive, more especially in the alteration produced by them in the Ledbeg marbles. They have been injected along the bedding-planes, and in some cases so regularly that it was at one time thought they were contemporaneous lava-flows. On the western face of Canisp a mass of porphyritic felsite rises from the old platform of Archæan gneiss, passing upwards into the overlying Torridon Sandstone and eventually spreading along the bedding-planes. Detailed mapping indicates the positions occupied by these igneous masses throughout the Torridon and Cambrian beds. It is considered that the outbreak of plutonic

[1] Vol. xxxvii. (1891) part i. p. 163.

activity in these ancient sedimentary systems must have been comparatively local. In the area lying to the west of the post-Cambrian movements these igneous rocks extend over a distance of about 9 miles from north to south, but in the region affected by those movements the distance is stated to be 24 miles. Originally they must have penetrated far to the eastward, for they are carried in a westerly direction with the associated sedimentary strata along the higher thrust-planes, indicating that the period of activity to which they belong is later than the Cambrian limestone of Durness and earlier than the post-Cambrian movements.

With few exceptions the rocks intrusive in the limestones are more basic than those in the quartzites, although hornblende-bearing rocks are common to both series. The Loch Borolan porphyry is described as an intrusive mass; the greater portion is highly granitoid, the prevalent type in the west being a coarse granitic rock consisting mainly of orthoclase with a little quartz, occasionally porphyritic with some mica; the second type, east of Loch Borolan, is characterized by dark garnets associated with orthoclase and a blue mineral, and may be foliated or non-foliated. This, I presume, is the rock described as 'Borolanite,' a group especially characterized by the association of orthoclase and melanite, and which naturally falls into the elæolite-syenite group, though in this case melanite is raised to the rank of an essential constituent. The action of the various intrusive masses and especially of the Loch Borolan porphyry upon the limestones is highly interesting; whilst the evidence of their physical relations to each other is brought forward in such a way as to leave little doubt that recognizable bands of Durness limestone have been converted into marble such as that of Ledbeg by contact with the eruptive rock.

It would be interesting to follow this subject further, more especially when one remembers what has been written about the Ledbeg marbles and the curious rocks associated with them, but the claims of other papers must be recognized, and there are yet three on Scottish matters, two of them relating more or less to the subject of contact-metamorphism. Taking these in the order of their appearance, the first is by Miss Gardiner on contact-alteration near New Galloway. It is, in the main, a microscopic paper and relates the changes produced in an alternating series of grits and shales towards the north-east of a granite-mass known as the Cairnsmore of Fleet. The Author notices the extreme variation in the degree of alteration undergone in different places at the same distance

from the granite, as for instance where grits are highly altered and shales but little affected. This certainly is just the reverse of what we should expect, unless the word 'grit' in this case implies something more than an assemblage of quartz-grains. She was, on the whole, disposed to believe that the variation in the amount of alteration at the same distances, the mode of alteration of the grits, and the transference of material might be accounted for by the passage of highly heated waters, and it was to the action of these that she mainly attributed the contact effect. It is just possible that this view may receive some countenance from the observation of Prof. Brögger that the chemical nature of the intrusive rock does, in certain cases, produce an influence on the character of the metamorphism. It is not easy to perceive how this could happen otherwise than through the convection of solvents. Mr. Barrow believes that Miss Gardiner's investigations have an important bearing on the origin of the crystallization of the Highland schists.

We have now to consider two papers, contributed by officers of the Survey, dealing with the subject of certain igneous rocks in the schists of the Highland border. The first of these, by Messrs. Dakyns and Teall, on the Plutonic Rocks of Garabal Hill and Meall Breac, is devoted to the description of some rocks which occur in a complex forming a belt of high ground almost immediately to the west of the lower end of Glenfalloch, on the confines of the counties of Perth, Argyll, and Dumbarton. These rocks are stated to vary considerably in chemical and mineralogical composition, and, although gradual passages are found between more or less acid varieties, in other cases the junction is sharply defined. The more acid are always found to cut through the less acid rocks, when the two are found in juxtaposition, and the fragments occurring in a rock are observed to be less acid than the rock itself. Although thus shown to be of different ages, they must clearly be referred to one geological period. This period was not defined by the Authors, but, to judge from the remarks of Mr. Barrow, the igneous mass is probably older than the Old Red Conglomerate, yet more recent than the general metamorphism of the Central Highlands. Basic rocks, mainly of the diorite type, but containing two notable bodies of peridotite, form a sort of fringe on the south-east side of the mass, which is, in this direction, considerably mixed up with the country schist owing to faulting; next comes an area of tonalite and non-porphyritic granite, and lastly, on the west side, a relatively large area of porphyritic granite of ordinary structure; in one locality only a gneissose structure may be observed, the planes of foliation curving round included

fragments. Since there is no evidence of any portion of the plutonic rock having been affected by earth-movements, in this case the Authors are disposed to attribute foliation to movements anterior to final consolidation.

The Authors conclude that in this area is the record of a series of events connected with the consolidation of a vast subterranean reservoir of molten rock, and the nature of the resulting complex they proceed to describe. The first rocks to be formed were peridotites; then followed diorite, tonalite, granite, and eurite (felsite) in order of increasing acidity. The most acid rock known occurs in narrow veins in the granite and tonalite, and is almost entirely devoid of ferro-magnesian constituents. Probably Mr. Barrow would suggest that this last rock represented the remains of the mother-liquor in which the granite, etc., had consolidated. The Authors further describe the physical features of many of the rocks, giving at the same time a detailed account of the constituent minerals. A comparison of the general distribution of these shows that, in this area (where it so happens that ordinary gabbros are absent), in proportion as the olivine dies out pyroxenes increase in importance, and these, in turn, are replaced by hornblende and biotite. Next the hornblende decreases relatively to the biotite, and finally, in the eurite-veins, the ferro-magnesian silicates have entirely disappeared. Turning to the quartzo-felspathic constituents and considering their distribution in the same way, it is observed that plagioclase first makes its appearance, then follows orthoclase and lastly microcline; quartz comes in with the orthoclase. It is instructive, they say, to note that when the minerals pyroxene, hornblende, biotite, plagioclase, microcline, and quartz make their first appearance, they play the rôle of groundmass; in other words, they are allotriomorphic or ophitic with respect to the other constituents. It is only when a mineral has established itself as an important constituent that it begins to show traces of idiomorphism. Thus in the order of formation of minerals a certain amount of overlapping takes place, and this overlapping is stated to reach its maximum in the plutonic rocks. The following order of occurrence, deduced from these investigations, accords on the whole with previous experience:—Iron-ores, olivine, pyroxene, hornblende, biotite, plagioclase, orthoclase, microcline, and quartz. Accessory minerals are singularly absent in the ultra-basic rocks.

Much attention has been paid by the Authors to the chemical composition of these rocks, and very interesting generalizations thus deduced. In accordance with precedent, a kind of chemico-minera-

logical scale is suggested, where we may imagine absolute basicity to be represented at one end by magnetite, and absolute acidity at the other end by free silica. The scale actually presented to us by Messrs. Dakyns and Teall, for the illustration of this particular group of rocks, does not reach the extreme possibilities at either end, though the range is very considerable. In the case now before us, it is found that, as the silica increases in a rock, magnesia—after iron-ores the most basic oxide—falls from a high position in the peridotites to almost nothing in the eurite-veins. Out of seven kinds of rocks selected to show the chemical sequence there is only a slight deviation from this law in one instance. Lime first rises and then falls, attaining its maximum in the biotite-diorite; after the fall has set in, it acts in sympathy with magnesia, whilst the iron-oxides follow suit. Alumina rises rather rapidly from a low position in the peridotites to a nearly level position in the diorites and granitites, falling somewhat in the eurite vein-rock. Of the alkalies, soda continues to rise for the most part, but with a somewhat marked fall in the eurite vein-rock. Potash rises throughout the series, except at the point where, as previously stated, there is a slight check in the otherwise uniform descent of magnesia. In the eurite vein-rock, which here represents the acidic termination of the sequence, potash is three or four times in excess of soda.

That somewhat similar views to those put forward by Dakyns and Teall are entertained by other petrologists may be perceived from a recent paper on the Basic Eruptive Rocks of Gran, in Norway, by Prof. Brögger. That Author confirms statements previously expressed to the effect that the different masses of eruptive rock, which occur within the sunken tract of country between Lake Mjösen and the Langesundsfjord, are genetically connected and have succeeded each other in regular order. In this particular case the oldest rocks are said to be the most basic, and the youngest (with immaterial exceptions) the most acid, whilst between the two extremes Prof. Brögger has found a continuous series. Several bosses of basic plutonic rock lie along a north-and-south fissure-line: the prevailing form is a medium or coarse-grained olivine-gabbro-diabase; but pyroxenites, hornblendites, camptonites, labrador-porphyrites, and augite-diorites also occur. Analyses of the typical rocks from three localities on the north-and-south line are given, and the conclusion is reached that the average basicity of the rocks forming different bosses decreases from north to south.

Of course, it is easy to see that the two cases are not exactly

parallel, since in the Norwegian case the rocks are all more or less basic, nor do we know the amount of field-evidence on which the genetic connexion between these several bosses is established. With regard to the rocks on the west side of Glenfalloch, we seem to have an assurance that such a sequence as the Authors have narrated actually exists within the area in question, and consequently that the important deductions which follow do not wholly depend upon petrological considerations. It is all very well to determine the order of crystallization of minerals in the cabinet, but if this philosophy is to be applied to large areas the evidence in the field must be above suspicion.

Very much the same views, as to the effects resulting from the order of crystallization, are expressed by Mr. Barrow in his paper on an Intrusion of Muscovite-biotite Gneiss in the South-eastern Highlands. The normal condition of the intrusive rock is that of a slightly foliated granite with two micas. The masses observed vary in size, and the larger ones are more or less fringed with pegmatite-veins, which cut the metamorphic schists in every direction, the foliation in the larger masses being rudely parallel to that of the surrounding schists. In the north-western portion of the area the intrusive rock is always a gneiss, and occurs in thin tongues which permeate the surrounding rocks. Towards the south-east these tongues amalgamate, and form large masses in which the foliation is less marked. Where the rock is a gneiss, it is composed of oligoclase, muscovite, biotite, and quartz, but contains no microcline. As the gneissic character becomes less marked, the oligoclase diminishes in amount, and microcline begins to appear, especially towards the margin of the masses, and in the most south-easterly of these microcline is greatly in excess of oligoclase. The differences in structure and composition are believed by the Author to be due to the straining off of the crystals of earlier consolidation during intrusion under great pressure. The still liquid potash-bearing portion of the magma was squeezed out and forced into every plane of weakness in the surrounding rocks; and that portion of it which contained the highest percentage of potash finally consolidated as pegmatite.

The phenomena of thermo-metamorphism, accompanying this intrusion of plutonic rock, are next considered. The rocks into which these igneous masses have been intruded are in a highly crystalline condition, and their grain is coarse, the micas being especially of large size. The general aspect of the north-western

portion of the district is gneissose, but as we proceed in a south-easterly direction towards the Highland border the rocks become finer in grain and more like the ordinary schists, finally assuming the phase of phyllites and of more or less crystalline arkose grits. This variation in the character of the rocks is accompanied by a change of the constituent minerals, more especially the aluminous silicates. It has been observed, for instance, that sillimanite, cyanite, and staurolite characterize three more or less distinct zones, which seem to be dependent on relative proximity to the igneous masses, since the zones do not necessarily coincide with the strike of the rocks. Thus, a thin bed of quartzite, which retains its character in consequence of the simplicity of its chemical composition, may be followed through all the zones, whereas the bed adjacent to it is:—in the outer zone a staurolite-schist, in the intermediate zone a cyanite-gneiss, and near the contact with the igneous rock a coarse sillimanite-gneiss. With regard to the two latter minerals, both of which have essentially the composition of andalusite, it may well be that the accession of heat alone, as pointed out by Mr. Teall, would be likely to convert cyanite into sillimanite, and thus the line separating these two minerals in that area might, to a certain extent, be regarded as an isothermal. With respect to staurolite, the Author allows that the zone of this mineral very nearly corresponds with the actual outcrop of a particular bed. In this case the original composition of the rock may have had something to do with its development. On inspecting the map which accompanies this paper, one cannot fail to observe that these three zones present a marked parallelism with the great mass of 'newer granite' on the confines of the counties of Forfar and Aberdeen; but the Author is of opinion that the metamorphism produced by these later granites can be easily distinguished from that which he has described, its effect having been to destroy many of the characters due to the earlier action.

Mr. Barrow considers that the sedimentary character of the rocks, as a whole, is established by their chemical composition. Limestones, shales, quartzites, and coarse grits may all be recognized in the metamorphic area. The lowest rocks, the quartzites of the North Esk Valley, are highly siliceous, though containing a certain amount of felspar, which both in the grits and gneisses is stated to be almost exclusively oligoclase. Even of those rocks whose origin may be regarded as more obscure there is nothing, he says, to suggest that they have been formed of crushed igneous material.

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among other noteworthy features they record the abundant occurrence of andalusite, in idiomorphic crystals, usually coated with little flakes of yellowish- or greenish-brown mica.

The study of the adjacent dykes and sills has led to some very interesting conclusions. Viewed as a whole, the neighbouring intrusions, while they have characters which seem to connect them, on the one hand, with the Shap Fell granite, and particularly with its darker patches, are unmistakably linked with the normal type of mica-traps found at greater distances. None of the various intrusions alluded to can be traced as continuous with the granite at the present surface, and the Authors suggest that, if they are right in regarding them as apophyses, these are in connexion, not with the visible granite-mass, but with a deep-seated extension of it. When these apophyses are considered in conjunction with the patches of darker rock caught up in the granite, they appear to throw light upon several of the dykes penetrating the Lower Palæozoic rocks of the district, which abound within a radius of 15 miles of the Shap granite. Numerous dykes, it is true, are found round the other granite areas of the Lake District, but these are usually felsitic, whilst the dykes more immediately in the neighbourhood of the Shap granite consist both of felsites and mica-traps—the latter chiefly on the east side, and especially in the region between Shap, Kendal, and Sedbergh. In the neighbourhood of the Shap granite both the felsitic and micaceous dykes have abundant porphyritic felspars, which imply a relationship to the granite itself, and such felspars are found to become rare at a distance from that outburst. As explanatory of these and other facts the Authors suggest that a magma occurred beneath the Shap granite of more basic character than the granite itself, and that from this the micaceous dykes were sent out, whilst some of this basic material also was carried up as 'clots' in the fluid granite. These, it is presumed, constitute the dark patches which attracted the attention of the late J. A. Phillips and other observers.

The nature of the Shap intrusion is further discussed, and it is argued that the abnormal alteration of the rocks around a mass with so small a diameter would suggest the passage of molten matter for a considerable period through the channel which is now filled with granite. In all probability such molten matter was for a long time forced from the underlying magma through this channel, though whether it terminated in a laccolite or in a volcanic outburst there is no present evidence to show. The rocks seen to be in contact with this old pipe are the Brathay Flags and other divisions

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the Shap granite, these Authors state they have since learnt that basic lavas are very widely distributed over the Lake District, and that the rocks on the north side of the intrusion must be placed in this division. Such rocks might with propriety be termed basalts, although, on account of the absence of olivine, some petrographers would prefer to call them basic andesites. The Authors again refer to the action of 'weathering' in connexion with this group, where some secondary products have remained as pseudomorphs of the minerals which generated them, while others, more soluble, have become disseminated through the mass of the rock, and especially collected in small fissures and in the vesicles with which the lavas abound. The basic lava of Low Fell contains 51 per cent. of silica as against 60 per cent. in the ordinary andesite, but nearly 3 times the amount of lime. Accordingly in the metamorphosed rock we find green hornblende more common than mica in the mass as well as in the contents of the vesicles. The ashes associated with the basic lavas, however, contain brown mica far more abundantly than hornblende, and the reason for this is seen in their low percentage of lime. Another principal difference is noticed in the abundance of epidote. Special attention is also devoted to the metamorphism of the infilled vesicles, and some important deductions are drawn from the phenomena observed.

After touching on some other points, the Authors conclude by stating their belief that thermo-metamorphism is not accompanied in general by any change in the chemical composition of the rocks affected. The exceptions are the partial loss of water and the expulsion, under certain conditions, of carbonic acid. In some districts it might be necessary to allow for the introduction of boric and hydrofluoric acids, but that does not apply here. Innumerable facts, they say, point to the conclusion that no transference of material has taken place except between closely adjacent points, and they are led to enquire what is the radius of the sphere of influence. This must to a certain extent vary according to the nature of the substance, and we must expect to find it greater at higher temperatures. As a test-case, they take the production of lime-silicates at the expense of calcite, and conclude that somewhere about $\frac{1}{20}$ inch would indicate the distance to which the interchange of lime and silica has demonstrably taken place. The impression produced by the study of other metamorphic minerals is in general accord with the above conclusion. Moreover, the dependence of the range of transfer of material upon temperature is well illustrated in the

case of the calcareous ashes of the Shap district, since, on the outer edge of the metamorphic aureole, it is only the most finely-divided calcite which has been decomposed.

In addition to the above, the Lake District has yielded three short papers which relate to the Skiddaw region. The first of these, by Mr. Groom, is on a tachylyte associated with the gabbro of Carrock Fell, and occurring in a vein about one inch thick. The rock to which the Carrock Fell tachylyte most nearly approaches appears to be the typical variolite of the Durance. It agrees with this rock in the nature and behaviour of the varioles (spherulites), in the character of the pyroxene-granules, and in the presence of a green groundmass. The tachylyte is regarded as of Ordovician age.

Mr. Postlethwaite has contributed two papers, which relate to eruptive rocks on the north-west side of Skiddaw. In Hause Gill, which lies nearly due north of the summit of that mountain, are two small exposures of a 'dioritic picrite' about $\frac{1}{3}$ mile apart, though probably forming one mass. This rock is described as being of a dark olive-green colour, and consisting of several varieties of hornblende with some felspar, serpentine, calcite, and other minerals. The Author remarks that it is still more remote from a typical picrite than the Little Knott rock, at no great distance, and it may be regarded as one of the transitional forms between normal picrite and normal diorite. He intimates that these eruptives may all have been derived from the same magma, since the differences are little more than have been shown to exist between different portions of the exposure at Little Knott itself. The chief interest in Mr. Postlethwaite's second paper centres in a comparison instituted between a sheet of diabase, intrusive in the Skiddaw series near Bassenthwaite, and a parallel bed of fine-grained grit. Half a century ago a considerable quantity of antimony was obtained from the locality. From the attendant circumstances he concludes that the deposition of the metalliferous vein-stuff has been the result of thermal action following the intrusion of the diabase.

Wales.—With respect to the Principality, there have been papers by Mr. Harker, Messrs. Cole and Jennings, and Prof. Lloyd Morgan, dealing with subjects which have been more or less touched upon by Sir Archibald Geikie in his first Presidential Address. On the present occasion we have to consider two papers by Miss Raisin and one by Messrs. Jennings and Williams.

The first of Miss Raisin's papers relates to the Nodular Felstones of the Lleyn. Not far from Afonwen Junction, on the south coast of this extreme promontory of Caernarvonshire, is a mass of igneous rock marked on the Geological Survey map 'Felspar-porphyry (intrusive) with agate-nodules.' The Author considers that the character of the rocks clearly negatives the theory of intrusion; they are old lava-flows, once glassy, now devitrified, and at Pen-y-chain are associated with interbedded agglomeratic and ashy strata. The mass of felstone near Pwllheli also contains similar nodular inclusions. These rocks must be classed as petrosiliceous, many structures being probably due to secondary devitrification. Everything, says Miss Raisin, points to subsequent silicification with attendant radialization in some cases. She suggests the percolation of heated waters carrying silica in connexion with the declining vulcanicity or solfatara-stage of the district.

These so-called 'agate-nodules' have long ago attracted attention. The large spherulites seem to have been developed either along certain strata or within masses of flow-brecciation, those near together being fairly equal in size. The spherulite seems to be the most durable part of the rock, which usually exhibits an originally vesicular character. The matrix surrounding the nodular spherulites consists for the most part of what must have been a compact, laminated, glassy lava, now devitrified, generally perlitic, and often spherulitic. The interior of the nodule is in many cases filled with chalcedony, and is not distinguishable in form from an original vesicle of the lava. These nodular structures are classed under the following groups:—contraction-spheroids, or magnified perlitic structure; masses resulting from flow-brecciation; solid spherulites or pyromerides; agate-nodules with an outer spherulitic crust; quartzose amygdaloids; and lastly spheroidal formations developed round a nucleus, such as an agate-nodule, a group of crystals, or an original vesicle of the lava.

With regard to the second of Miss Raisin's papers, I would remark that the subject of Variolite has latterly assumed considerable interest and importance amongst British geologists, both from the fact that this remarkable rock has been discovered at more than one point in the United Kingdom, and also because it has formed the basis of some important communications to the Society. A very brief allusion to two papers relating to foreign localities may not be altogether out of place in this connexion.

Thus, in their paper on the Variolitic Rocks of Mont Genèvre,

Messrs. Cole and Gregory tell us that the variolite of the Durance occurs *in situ* as a selvage on the surface of certain diabases, also as blocks in the associated fragmental rocks which are apparently tuffs, and occasionally as a selvage to diabase-dykes. This product of rapid cooling was originally a spherulitic tachylyte, and has become devitrified by slow secondary action. In fact, they say that variolite stands in the same relation to basic lavas as pyromeride does to those of an acid character. These eruptive rocks are probably of post-Carboniferous age, and there are several other areas of similar variolitic rocks both in the Alps and the Apennines. The best modern representative of the conditions that produced such rocks is to be found in the great volcanoes of Hawaii.

In the succeeding volume of the Quarterly Journal Mr. Gregory gave the results of his examination of the variolitic diabase of the Fichtelgebirge as deduced from the neighbourhood of Berneck. This, he concludes, is intrusive into rocks of Devonian age. The variolitic structure is found to occur in two different arrangements, viz.:— on the surface of spheroidal masses of compact diabase; and, secondly, as a true contact-product on the selvage of the diabase, the varioles being true spherulites. He also concluded that, although the varioles are the product of rapid cooling, too sudden a solidification of the diabase may prevent their formation.

Returning now to the consideration of Miss Raisin's paper on the Variolite of the Lleyn, it would appear that the first discovery of this rock in Britain was made by Prof. Blake at Careg Gwladys in Anglesey, as announced at the meeting of the British Association in 1888.[1] Subsequently Prof. Cole described a rock of this description from Annalong, in the county Down.[2] According to the statement of Prof. Bonney, Miss Raisin's discovery of Variolite at the Lleyn affords the third example of this kind of rock in the British Isles. The specimens described by that lady occur at Aberdaron, and also at one or two localities on the west coast of the Lleyn in a district which was marked on the Survey Map as 'Metamorphosed Cambrian.' Amongst the rock-specimens not hitherto described, Miss Raisin includes forms of variolite, a spherulitic, somewhat basic rock. The igneous masses which contain these are stated to belong to the class of rather basic andesites, or not very basic basalts: corresponding to these two types of rock are two forms of variolite. Their general microscopic structure and development are described

[1] Brit. Assoc. Rep. 1888 (Bath Meeting), p. 411, pl. v. fig. 22.
[2] Sci. Proc. Roy. Dub. Soc. vol. vii. (1892) p. 513.

with considerable detail, the Author observing that variolite has been defined as a 'devitrified spherulitic tachylyte, typically coarse in structure,' though she is disposed to place her own interpretation upon the last phrase. The phenomena observed correspond in many respects with those of the Durance and the Fichtelgebirge, as noted by the Authors quoted on the preceding page. As regards the age and associations of these variolite-bearing rocks of the Lleyn, there are volcanic rocks including lava-flows, and fragmental masses both of fine ash and coarse agglomerate. These are found in company with limestones, grits, and other rocks, which are possibly of sedimentary origin. Without suggesting any particular age. Miss Raisin considers these variolite-bearing rocks to be of high antiquity.

The neighbourhood of Ffestiniog is so well known to tourists, and especially to artists, from the picturesqueness of its scenery, that some account of its geological structure might seem to possess a popular as well as a scientific interest. The paper by Messrs. Jennings and Williams on Manod and the Moelwyns is a contribution in this direction. The area described by these Authors forms part of the northern ring of the Merionethshire anticlinal; the Upper Cambrian strata dip under the mountains which give the title to this paper, and are there overlain by ashes and slates of Arenig age. Apart from the palæontological and stratigraphical evidence offered by the Authors with respect to the Lower Palæozoic rocks of this district, they show the intrusive nature of the great crystalline mass known as the syenite or granitite of Tan-y-Grisiau, and to its intrusion they attribute the metamorphism of the surrounding rocks. This, then, is another case of contact-metamorphism, though it does not appear that any of the characteristic minerals are largely developed. Round the junctions the sedimentary rock is altered into a compact *hornfels*, and in some places it is very difficult to distinguish the altered rock from the finely crystalline edge of the granitite. Judging from the map which illustrates this paper, the surface-exposure of the granitite lies wholly within Tremadoc rocks; but, in spite of what the Authors call the intensity of the metamorphism, there is a striking absence of distinct crystals. The brown mica so common in areas of contact-alteration is absent throughout. In some cases, where spots are developed, these have a tendency to quadrilateral form, and may, in the Authors' opinion, be embryo crystals of andalusite; but there is nothing resembling the rocks of the altered region about Skiddaw. This deficiency may be

due, amongst other possible causes, to the original nature of the containing rocks, of which, they say, it is difficult to speak with certainty. An alternative but less probable supposition is, that it may in part have been due to some peculiarity in the nature of the intrusive rock. This is an acid granite with potash considerably in excess of soda, very poor in ferro-magnesian silicates and abounding in quartz. It has been subjected to considerable strain and crushing, a circumstance which has suggested a comparison with the rock of Bryn-y-Garn near St. David's. An analysis of this granitite compared with that of the eurite of Cader Idris shows that this is slightly the more acid rock of the two, whilst the proportion of the alkalies is nearly reversed.

Devonshire.—About half a dozen papers relate more or less to petrological questions connected with this county, but as those especially dealing with the volcanic history of the region have already been noticed, it would be superfluous to allude to such matters again. In his paper on the elvans and volcanic rocks of Dartmoor, Mr. Worth has described two elvanite-dykes in the neighbourhood of Tavistock for the purpose of demonstrating the structural changes which they exhibit. One of these shows a centre composed of quartz-felspar-porphyry passing laterally through numerous varieties into 'claystone'-porphyry. The other dyke, when traced for some distance, exhibits a change from a fine-grained porphyritic granite to a rock with a compact semivitreous ground mass, in which felspar, quartz, and mica are porphyritically developed.

Mr. Bernard Hobson has lately contributed a paper on the Basalts and Andesites of Devonshire, known as 'felspathic traps.' According to this writer it would seem that all but one of the specimens examined are olivine-basalts. He feels no doubt of the contemporaneous nature of the lavas exposed in all the localities visited. This conclusion is in accordance with the views of De la Beche, and contrary to the statement of Mr. Vicary that "they commonly appear as dykes filling fissures in the earlier rocks." In some places the basalt, as he calls it, may be seen to intervene between the underlying Carboniferous and the overlying Permian (or Triassic) rocks. Mr. Hobson doubts the connexion of these lavas in any way with the Dartmoor granite, since the so-called 'felspathic traps,' being really olivine-basalts, are not likely to be the effusive equivalents of the granite. He also doubts the intrusion of quartz-

porphyries into the 'felspathic traps.' The presence of quartz-inclusions misled De la Beche into terming these rocks 'quartziferous porphyries.'

It would hardly be possible to broach the subject of Devonian geology without some allusion to the Dartmoor granite. Why the igneous origin of this particular granite should have been attacked any more than that of any other is, perhaps, difficult to explain. It is bigger and more accessible than most of our English granite-masses, and having become, as it were, a stock subject, is exhibited from time to time by the demonstrators in different attitudes to please the fancy of various audiences. The latest difficulty, it would seem, arises from the supposed want of a satisfactory explanation of the structural relations of the granite to the surrounding rocks. Thus Mr. Ussher has recently announced that "from the relations of the stratified rocks to the granites of Devon and Cornwall there is no obtainable evidence as to the upheaval of the latter."[1] Consequently the view is advanced that the granite of Dartmoor resulted from the metamorphism of pre-existing rocks which had, in a rigid state, exercised an obstructive influence on the north-and-south movements, and had thereby produced great mechanical effects on the surrounding strata.

These views of Mr. Ussher were criticized by General McMahon, in a paper entitled 'Notes on Dartmoor,' read before the Society towards the close of last session. The Author gave some of the results of a visit to the western borders of Dartmoor, detailing certain cases of eruptive granite-veins intruding into the Culm-measures in the immediate vicinity of the main mass of granite. The latter, in the locality described, is porphyritic down to its boundary, and the veins are also porphyritic. All the circumstances led the Author to believe that these veins are real apophyses from the main mass, and that the view adopted by De la Beche regarding the origin of the Dartmoor granite is the true one. He further commented on the improbability that a tremendous squeeze, sufficient to fuse such a mass of pre-Devonian rock into granite, should have left the Culm-measures, outside the zone of marginal contact-metamorphism, almost untouched. It may be that Mr. Ussher's views on this subject have been somewhat misunderstood, and an attempt was made to show that this was so. But whatever they may be, there is such a touch of vagueness about 'pre-Devonian' rock that we may hope for a further revelation on this score.

[1] Geol. Mag. 1892, p. 467.

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micaceous sediment being much more general in the southern area than farther north. The comparison between the mica-schists of the Start region and the Devonian slates is scarcely attempted; but much stress is laid upon the analogy between the green rocks of the metamorphic area and what he calls Devonian volcanics. As regards the character of the metamorphosis generally, he discusses certain chemical questions, not forgetting hydrothermal action, and proceeds to state that with magnesia and carbonic acid available from an outside source the process of metamorphism seems easy. Lastly, he concludes that there is evidence in support of the hypothesis that the metamorphic rocks of South Devon are Lower Devonian, and of about the same age as the sandstones and slates with *Pleurodictyum problematicum* of the northern shore of Torbay.

The notion of the Devonian age of the Start Schists has generally found favour at Torquay, and recently, as we perceive, authors have so far grappled with the details that they venture to specify the Lower Devonians as the beds whose metamorphism has produced the rocks in question. Now, we have learnt from Mr. Ussher's paper, already quoted under 'Devonian,' that the Lower Devonians on the north side of the Dart are devoid of interbedded igneous rocks, and that they are essentially a gritty series with some slates towards the top. But it would seem that the presumed Lower Devonians on the south-west side of the Dart do contain interbedded sheets of igneous rock, and it is the supposed metamorphism of these which it is thought may have given rise to the 'green rocks' of the Start. Admitting, then, for the sake of argument, that a diabase might, under certain circumstances, become a "felspathic green rock of gneissoid character, containing compact hornblende, much fibrous hornblende, and chlorite," is there anything like a proportionate development of the diabase-rocks of the presumed Lower Devonian of the Torcross district and the 'green rocks' of the metamorphic area?

This question, of course, can only be answered by geologists who have made the locality their special study. But apart from Lower Devonian diabases, which in some districts are not by any means in evidence, it would seem that the arenaceous Lower Devonians in general require a considerable amount of bolstering up before they could be made to yield rocks like the general type of the South Devon Metamorphics. Thus, for instance, Mr. Hunt is obliged to postulate an excess of micaceous sediment for the

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suggested that the banding of the hornblende-schists was produced by the action of water, such as circulates about the roots of volcanoes, leaching out unstable minerals, like pyroxene, from the spaces between the planes of lamination, and the formation of comparatively stable minerals, such as hornblende, along those planes. The Lizard rocks he regarded as containing good examples of the formation of hornblende in the wet way, that mineral having been deposited in cracks so as to join together the ends of hornblende crystals. The Author considered the 'granulitic' group as in part the result of converted ash-beds, whilst other portions are composed of intrusive diorites of later date, the quasi-bedded appearance of both being due to the injection of granite. In some places the intrusive character of the granitic veins is undoubted. On the whole, it would seem that this paper was written at a time when the Author wished to protest against every case of foliation being quoted as an instance of dynamic deformation, though on several points he was content to suspend his judgment for the present.

The next paper on the Lizard Rocks was a joint contribution from Prof. Bonney and General M^cMahon, being the results of a visit in August 1890. The Authors maintained that the peridotite, from which the serpentine is derived, was introduced into the hornblende-schist and banded granulitic rocks, after these had assumed their present condition. They assert that there are no signs of any marked pressure-metamorphism in this rock either prior or posterior to serpentinization. The streaky or banded structure they have failed to connect with any foliation or possible pressure-structure in the schists, and they are disposed to regard it as resulting from movements while the mass was still in a molten or partially molten condition. The occasionally banded structure in the gabbro they also regard as resulting from a kind of fluxional structure. They now held that the 'granulitic' group consists of at least two distinct rocks—one acid, the other basic,—of which the former was intrusive in the latter, and that, certain fluxional movements ensuing, the uniform and stratified aspect of the two varieties was thus produced: this movement being followed by crystallization, or completion of crystallization, in the constituents. The hornblende-schists they were content to leave a somewhat open question; and, lastly, they held that earth-movements have produced marked effects only at the extreme north and the extreme south of this district, those on the northmodifying the rocks for a very limited distance.

The latest communication to the Society on the subject of the

Lizard Rocks was furnished last session by Messrs. Fox and Teall, who gave a very close description of two limited districts, viz. that of Ogo Dour and that of the Lion Rock near Kynance. In the former district they conclude that the hornblende-schist and serpentine form together a banded complex of crystalline foliated rocks, and that if there is any material difference in age the serpentine is likely to be the earlier of the two. This, it should be stated, is an olivine-hornblende serpentine, markedly different from the common variety. The complex of schist and serpentine has been folded after the banding was produced, and before the dykes were intruded, whilst some, if not all, of this folding probably took place when the complex was formed. The schist and the serpentine are traversed by dolerite-dykes, which have themselves been converted into schists, macroscopically indistinguishable from portions of the normal hornblende-schist of the Lizard peninsula; faulting has taken place after the dykes had reached their present condition.

In the Lion Rock district the relations between the serpentine and the 'granulitic' group are considered. The main mass of the cliff here is formed of serpentine, of which the common variety weathers red and contains numerous crystals of bastite. Basic dykes and a gabbro-vein are observed to traverse this, and these dykes pass occasionally into hornblende-schist. Moreover, they vary in thickness, and in some of the thicker portions put on appearances which are characteristic of the 'granulitic' group. In the section a wedge-shaped mass of typical 'granulitic' rock is seen surrounded by serpentine, and the structure of this mass appears to be incompatible with the theory that the serpentine was intruded into it when solid.

As an interesting appendage to this paper the same Authors gave an account of a Radiolarian Chert from Mullion Island, with the addition of critical notes by Dr. Hinde. This paper might indeed have been included in the Palæontological division, but as a matter of convenience it is placed along with the rest of the communications relating to the Lizard. The stratified rocks, which form only a small portion of the island, consist of chert, shales, and limestone, occurring as thin strips or sheets and sometimes as detached lenticles within the prevailing mass of 'greenstone,' possibly representing a subaqueous lava. The chert is of radiolarian origin, and the radiolaria are often recognizable on the weathered surface of the beds. Dr. Hinde gave a technical description of the recognizable forms, the genera being included under the suborders

Sphæroidea and Prunoidea. Without distinctly stating the age, he went so far as to remark that, in their general condition of preservation, the radiolaria in this Cornish chert strongly resemble those in the Ordovician chert of Scotland. Messrs. Fox and Teall regard Mullion Island as belonging to the sedimentary series which, on the mainland, is faulted against the Lizard rocks, although they failed to find the particular beds of the island in any part of the immediate neighbourhood.

To judge from the foregoing extracts it cannot be doubted that considerable progress has of late been made towards a recognition of the true character of the Lizard rocks, which, for the extent of territory they occupy, are perhaps without equal in point of interest throughout the British Isles. Prof. Bonney may be said to have rediscovered these rocks about seventeen years ago, and his recognition of the true origin of the serpentine laid the foundation for the correct diagnosis of the entire peninsula, whilst it put an end to a considerable amount of crude speculation. Another phase in the history of the Lizard dates from the publication of Mr. Teall's instructive paper on the Origin of certain Banded Gneisses,[1] wherein he contended that a series of rocks, hitherto regarded as sedimentary, are really of igneous origin, and that the parallel structure which characterizes many of them has nothing to do with stratification in the ordinary sense of the word, but is a consequence of the deformation to which the original rock-masses have been subjected.

Practically there is now no dispute, one may say, as to the character of these banded gneisses, which present an appearance so curiously imitative of sedimentation; and although there may be a slight reserve in some quarters as to the possibly pyroclastic origin of a portion of the hornblende-schist, the rocks of the Lizard peninsula, as a whole, are regarded by all as truly igneous. Amongst the more important issues which yet remain for decision is the question as to how far the peculiar structure of the banded gneisses is due to deformation, or to some congenital peculiarity as suggested by General McMahon. The next question seems likely to prove a thorny one, viz. the determination of the order of succession in the several igneous masses. This latter point is really not one of prime importance, since practically the Lizard rocks, for the most part, are of one age, and constitute an igneous—possibly a plutonic—complex, portions of which have been folded, and the whole thrown into such confusion that the story told by one section may perhaps

[1] Geol. Mag. 1887, p. 484.

be contradicted by the next. It is interesting to bear in mind certain points of resemblance between the Lizard district and the North-west Highlands indicated by Mr. Teall, more especially as regards foliated crystalline rocks being cut by basic dykes, which themselves pass into schists. So far as it goes, this evidence is in favour of the generally accepted view that the Lizard rocks are of Archæan age. Whether the whole mass segregated from a homogeneous magma as held by Mr. Somervail,[1] or whether the relations of the several rock-masses are those of intrusion, is perhaps a question which cannot be very easily answered. Should the former view be the correct one, in that case, according to the accepted determination of the order of crystallization, which we have seen applied by Messrs. Dakyns and Teall, and quite lately by Prof. Brögger, the now serpentinized peridotite must have been the earliest rock to consolidate.

Britanny and the Channel Islands.—A study of the older rocks of this region may be expected to throw some light on the problems suggested by the Lizard, and for this reason I venture to cross the English Channel. The principal authors in this field have been Prof. Bonney and the Rev. Edwin Hill. It is now nearly eight years since the excursion of the Geological Society of France to Britanny drew the attention of geologists to that peninsula. Dr. Charles Barrois, of Lille, prepared on that occasion an excellent summary of the geological constitution of Finistère for the use of the excursionists, amongst whom was Mr. Hill. Prof. Bonney acknowledges his obligations to both these gentlemen in the preparation of his notes on the structure and relations of some of the older rocks of Britanny. He expressly says that he did not go there to criticize but to compare, and to ascertain the bearing of the rocks of Britanny upon general questions of metamorphism and the genesis of crystalline schists. He noticed certain glaucophane-amphibolites and associated schists, which he considered as undoubtedly of igneous origin, but subsequently modified by pressure. The banded gneiss at the embouchure of the Pouldu and at Roscoff, especially the latter, constantly reminded him of the more typical members of the 'granulitic' series at the Lizard, the structures of which are very difficult to explain on any theory of a 'rolling-out' of a complicated association of igneous rocks. At that time he concluded that, while the structures of some foliated rocks may be

[1] Geol. Mag. 1892, p. 364.

regarded as primarily due to pressure operating upon suitable materials, the structure of others seemed opposed to this explanation; but, whatever the genesis of these rocks, they are rightly called Archæan gneisses and schists.

Simultaneously with the last paper appeared one by Mr. Hill on the Rocks of Sark, Herm, and Jethou. The greater part of the island of Sark consists of dark hornblendic banded rocks, which closely resemble those of the Lizard. Owing to certain appearances, which he describes, the Author at that time concluded that these rocks originated through some kind of successive deposition, if not actually from aqueous sedimentation. He thus sums up what appears to have been the order of geological events:—A mass of Archæan rock of uncertain origin (the Creux-Harbour gneiss) had deposited on it a thick series of beds of alternating materials, principally hornblendic, possibly of volcanic origin. Over these a mass of granitic or syenitic igneous rock subsequently flowed. After the solidification of this, but still probably at a very early period, came a great east-and-west nip. Except certain intrusive dykes there are no later materials with which to continue the history of Sark. Mr. Hill further insists upon the Archæan age of these rocks being analogous to rocks elsewhere admittedly pre-Cambrian. They seem distinctly older, he says, than the unfossiliferous argillites of Jersey, themselves of extreme antiquity. Some of the views expressed in this paper have been materially modified quite recently, but before considering these matters it will be convenient to proceed with Mr. Hill's next paper on the Channel Islands.

This relates to the rocks of Alderney and the Casquets. Alderney itself consists for the most part of crystalline igneous rocks, to which the name of granite may be applied. The general appearance of this is said to recall the diorites and syenites of Guernsey, but the abundance of mica and the smaller amount of hornblende connect it rather with the granites of Jethou and Sark. The minor intrusives are next described, one of the most interesting being a dark holocrystalline rock of high specific gravity, approaching somewhat near to a picrite—the first instance known to Mr. Hill in these islands of an olivine-bearing rock.

The grits constitute an important formation, which may be traced at intervals from the Casquets on the extreme west to a point east of Cherbourg—a distance of 30 miles. The Author remarks that the current-bedding, arkose materials, and sporadic pebbles, point to the immediate neighbourhood of a coast similar to the present

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and associated with these are banded gneisses characterized, as a whole, by more micaceous bands, some being fairly rich in biotite. Certain of these gneisses resemble the 'granulitic' group of the Lizard, and they are spoken of as being occasionally much 'gnarled' by subsequent earth-movements after the characteristic structure had been assumed. But the most remarkable petrological feature of the island is the occurrence of masses of hornblendite, which are not restricted to any very definite horizon, though they are most common either just above the basement-gneiss or at no great height up in the overlying series.

In some places large masses of this dark-green hornblende-rock are broken up and traversed by a pale red vein-granite or aplite. The former rock is drawn out into irregular lenticles, elongated lumps, and finally streaks, and has been melted down locally into the aplite, the result being a well-banded biotite-gneiss, agreeing with types which are common amongst the Archæan rocks. The Authors believe, therefore, that Sark presents an example of the genesis of such a gneiss, and they, moreover, are of opinion that probably all the above-named rocks are of igneous origin, but became solid ultimately under somewhat abnormal conditions, to which the peculiar structures (which distinguish them from ordinary igneous rocks) are due. They attribute the banding to fluxional movements, anterior to final consolidation, in a mass to some extent heterogeneous. This hypothesis, they consider, may be applied to all gneisses or schists which exhibit similar structures—that is, to a considerable number of the Archæan rocks.

Apart even from the important change of front exhibited in the last paper with respect to rocks showing 'stratification-foliation,' these communications on the Channel Islands and adjacent mainland are replete with interest to the British geologist. Seen in the light of modern research, there could have been no objection to grouping the several crystalline formations of the Channel Islands under the heading 'Fundamental Rocks.' But when it is remembered that the Jersey conglomerates were once thought to be of Triassic and the Jersey rhyolites of Permian age, it seemed safer to consider the whole matter under the heading 'Petrology,' rather than beg the question, as it were, by grouping them with the Fundamental Rocks. Nevertheless, there can no longer be any doubt as to the Archæan age of most of these crystalline masses, though perhaps all are not agreed as to the precise interpretation of the word 'Archæan.' We seem, indeed, here to recognize a Lower and an

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less valuable because it requires a certain amount of special training in order that it may be appreciated.

And this reflection serves to remind me of the immense amount of work that has been accomplished in England since the Fathers of Geology laid the foundations of the science. Without alluding especially to the valuable Memoirs of the Geological Survey, I may venture to call your attention to the circumstance that, in December last, the Geological Magazine saw the end of its third decade, and has now entered upon its 31st year. The value of this important auxiliary has long been recognized by geologists, who cannot be too conscious of the debt they owe to its truly independent Editor, now, I am happy to say, your President-elect. Nor must we forget that this year will mark the Jubilee of our own Quarterly Journal, and that for this solid work of half a century a suitable Index is in course of preparation. It has at times occurred to me that, unless some modification is made in the rules which require entire originality in papers intended for publication, there may be difficulty at a future date in obtaining a sufficiency of matter to interest the Fellows in the work which is going forward. However, the future does not so much concern an outgoing President as the past; and glancing at this once more, I may safely assert that if a student wishes to keep in touch with modern geological research he should diligently study the recent volumes of our Quarterly Journal.

February 21st, 1894.

Dr. Henry Woodward, F.R.S., President, in the Chair.

Thomas Hargreaves, Esq., Secretary of the Institute of Mines and Forests of British Guiana, Georgetown, British Guiana; William Maynard Hutchings, Esq., 99 Osborne Road, Newcastle-on-Tyne; Alfred Edouard Lardeur, Esq., 64 Stamford Street, Blackfriars, S.E.; John Nevin, Esq., Littlemoor, Mirfield, Yorkshire; and the Rev. James Thomas Pinfold, Mornington, Dunedin, New Zealand, were elected Fellows of the Society.

The List of Donations to the Library was read.

The President announced that the Sixth Session of the International Geological Congress will be held at Zürich from August 29th to September 2nd, 1894. The meetings are to be divided into three sections:—

1st. General Geology, etc.
2nd. Stratigraphy and Palæontology.
3rd. Mineralogy and Petrography.

Geologists having papers to present at the Meetings are requested to notify the same to the Committee, and to send a short abstract of the subject with which they propose to deal. The Circular is suspended on the Notice-Board at the Apartments of the Society for the convenience of those Fellows who may desire further information.

The following communications were read:—

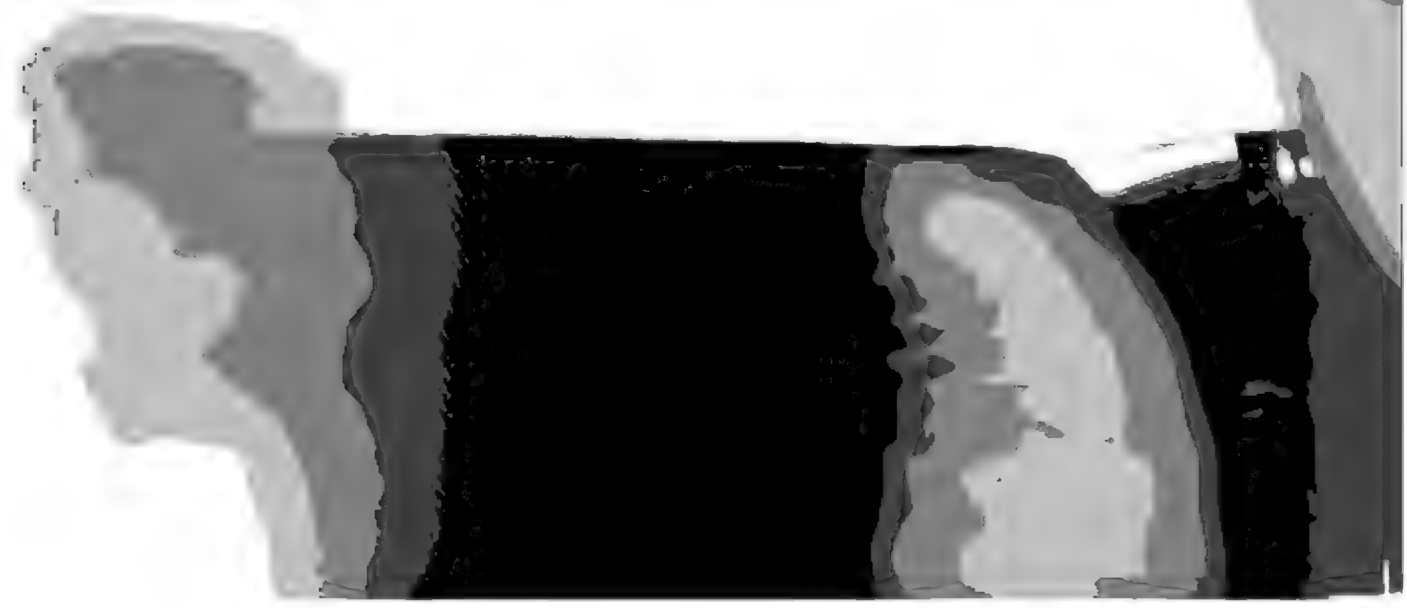
1. 'On the Relations of the Basic and Acid Rocks of the Tertiary Volcanic Series of the Inner Hebrides.' By Sir Archibald Geikie, D.Sc., LL.D., F.R.S., F.G.S.

2. 'Note on the Genus *Naiadites*, as occurring in the Coal Formation of Nova Scotia.' By Sir J. William Dawson, C.M.G., LL.D., F.R.S., F.G.S. With an Appendix by Dr. Wheelton Hind, B.S., F.R.C.S., F.G.S.

The following specimens were exhibited:—

Photographs and rock-specimens from near the head of Glen Sligachan, Skye, exhibited by Sir Archibald Geikie, D.Sc., LL.D., F.R.S., F.G.S., in illustration of his paper.

Specimens exhibited by Sir J. William Dawson, C.M.G., LL.D.,



F.R.S., F.G.S., and Dr. Wheelton Hind, B.S., F.R.C.S., F.G.S., in illustration of their paper on the Genus *Naiadites*.

Specimen of Cave-sandstone (Jurassic) from the Harrismith District, Orange Free State, exhibited by David Draper, Esq., F.G.S.

March 7th, 1894.

Dr. Henry Woodward, F.R.S., President, in the Chair.

James W. Bradley, Esq., Assoc.M.Inst.C.E., Oulton Villa, Nelson; J. A. Foote, Esq., Ceres, Cupar-Fife; Thomas Edward Knightley, Esq., Cleve House, Tulse Hill, S.W.; and Leonard James Spencer, Esq., B.A., 16 Barclay Road, Walham Green, S.W., were elected Fellows of the Society.

The List of Donations to the Library was read.

The Secretary announced that a portrait of the late Sir Richard Owen, K.C.B., F.R.S., F.G.S., had been presented to the Society by Ernest Swain, Esq., F.G.S.

The following communications were read:—

1. 'The Systematic Position of the Trilobites.' By H. M. Bernard, Esq., M.A., F.L.S., F.Z.S. (Communicated by Dr. Henry Woodward, F.R.S., P.G.S.)

2. 'Landscape Marble.' By Beeby Thompson, Esq., F.G.S., F.C.S.

3. 'On the Discovery of Molluscs in the Upper Keuper at Shrewley, in Warwickshire.' By the Rev. P. B. Brodie, M.A., F.G.S.

The following specimens were exhibited:—

Specimens exhibited by Beeby Thompson, Esq., F.G.S., F.C.S., in illustration of his paper.

Arborescent Limestone and Cotham Marble, exhibited by the Director-General of the Geological Survey.

Arborescent Dendritic Markings on a specimen of Lithographic Stone from Solenhofen, exhibited by the President.

Molluscan Impressions (Lamellibranch Shells) from the Upper Keuper Sandstone of Shrewley, Warwick, exhibited by the Rev. P. B. Brodie, M.A., F.G.S., in illustration of his paper.

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The List of Donations to the Library was read.

The following communications were read :—

1. 'Mesozoic Rocks and Crystalline Schists in the Lepontine Alps.' By T. G. Bonney, D.Sc., LL.D., F.R.S., F.G.S., Professor of Geology in University College, London, and Fellow of St. John's College, Cambridge.

2. 'Notes on some Trachytes, Metamorphosed Tuffs, and other Rocks of Igneous Origin, on the Western Flank of Dartmoor.' By Lieutenant-General C. A. McMahon, F.G.S.

The following specimens were exhibited :—

Rock-specimens and microscope-sections, exhibited by Prof. T. G. Bonney, D.Sc., LL.D., F.R.S., F.G.S., in illustration of his paper.

Rock-specimens and microscope-sections, exhibited by Lieut.-General C. A. McMahon, F.G.S., in illustration of his paper.

Specimen of Ecca Conglomerate from near Grahamstown, Cape Colony, exhibited by Dr. J. W. Gregory, F.G.S.

April 25th, 1894.

Dr. Henry Woodward, F.R.S., President, in the Chair.

John Charles Burrow, Esq., Trelowarren Street, Camborne, Cornwall; and Charles Davison, Esq., M.A., 373 Gillott Road, Birmingham, were elected Fellows of the Society.

The List of Donations to the Library was read.

Mr. A. R. Sawyer, referring to specimens exhibited by him from the Transvaal, Orange Free State, Cape Colony, Mashonaland, and Matabeleland (the last mentioned collected during the recent war), remarked that gneisses and gneissose granites cover a large portion of Mashonaland, together with patches of schistose rocks and a few stratified rocks. He drew attention to the fantastic shapes assumed on weathering by the granitic gneiss, which he considered solely due to atmospheric agencies, and not to ice-action or to the effects of submersion.

The schistose rocks are, for the most part, sheared and altered igneous masses. There are numerous examples of dolerites and epidiorites passing into hornblende-schists, and of more acid igneous rocks. Masses of magnetite occur in various parts of Mashonaland, and serpentinous rocks (which probably owe their origin to the alteration of peridotites) in the N.W. corner of the Victoria Gold-field.

Extremely auriferous veins occur amongst the sheared acid igneous rocks of the Umhungwe Valley in the Manica district, and gold occurs in the kaolin produced by the disintegration of these rocks.

The following communications were read:—

1. 'Further Notes on some Sections on the New Railway from Romford to Upminster, and on the Relations of the Thames Valley Beds to the Boulder Clay.' By T. V. Holmes, Esq., F.G.S.

2. 'On the Geology of the Pleistocene Deposits in the Valley of the Thames at Twickenham, with Contributions to the Flora and Fauna of the Period.' By J. R. Leeson, M.D., F.L.S., F.G.S., and G. B. Laffan, Esq., B.Sc., F.G.S.

3. 'On a Goniatite from the Lower Coal Measures.' By Herbert Bolton, Esq., F.R.S.E. (Communicated by George C. Crick, Esq., F.G.S.)[1]

In addition to the specimens mentioned on p. 144, the following were exhibited:—

Specimens from the new Railway from Romford to Upminster, exhibited by T. V. Holmes, Esq., F.G.S., in illustration of his paper.

Specimens of the Fauna and Flora from the Pleistocene Deposits at Twickenham, exhibited by Dr. J. R. Leeson, F.L.S., F.G.S., in illustration of the paper by himself and G. B. Laffan, Esq., B.Sc., F.G.S.

Specimens of *Goniatites*, exhibited by Herbert Bolton, Esq., F.R.S.E., in illustration of his paper.

Palæolithic Flint-implement, found in Gravel at the corner of Jermyn Street and Eagle Place, S.W., April 4th, 1894, exhibited by the Director of the Museum of Practical Geology.

May 9th, 1894.

Dr. Henry Woodward, F.R.S., President, in the Chair.

Colonel Frederic Taylor Hobson, 83 Queen's Gate, S.W., was elected a Fellow of the Society.

The List of Donations to the Library was read.

[1] This paper has been withdrawn by permission of the Council.

Mr. Lydekker exhibited some specimens from a collection of Argentine fossil Vertebrates which he had been allowed to select from the La Plata Museum for presentation by Dr. Moreno to the British Museum. Many of these belonged to types previously quite unrepresented in the collection of the latter. He also drew attention to his recently published monograph on Argentine Vertebrates, and stated that he hoped these results of his journey to La Plata under the auspices of the Royal Society would be regarded as satisfactory. The difficulty he himself had laboured under, in endeavouring to understand what had been previously written in regard to the extinct mammals of Argentina, was largely due to the absence of satisfactory figures; and his object had, therefore, been to figure as many specimens as possible on a large scale, in order that others might have an opportunity of judging for themselves, quite apart from his own descriptions and conclusions.

He had undertaken his journey to Argentina somewhat unwillingly, at the wish of Sir W. H. Flower and Mr. Sclater; but he had been so interested in what he had seen, that he hoped means might be afforded him of repeating his visit this year.

The following communications were read:—

1. 'Carrock Fell: a Study in the Variation of Igneous *Rock-masses*.—Part I. The Gabbro.' By Alfred Harker, Esq., M.A., F.G.S.

2. 'The Geology of Monte Chaberton.' By A. M. Davies, Esq., B.Sc., F.G.S., and J. W. Gregory, D.Sc., F.G.S.

3. 'Cone-in-Cone. How it occurs in the Devonian (?) Series in Pennsylvania, U.S.A., with further details of its Structure, Varieties, etc.' By W. S. Gresley, Esq., F.G.S.

In addition to the specimens described by Mr. Lydekker (see above) the following were exhibited:—

Rock-specimens and microscope-sections, exhibited by Alfred Harker, Esq., M.A., F.G.S., in illustration of his paper.

Specimens and microscope-sections, exhibited by A. M. Davies, Esq., B.Sc., F.G.S., and Dr. J. W. Gregory, F.G.S., in illustration of their paper.

Flint-implements, etc., from Bournemouth, Christchurch, Wells (Norfolk), and Shoreham (Kent), exhibited by the Rev. R. Ashington Bullen, B.A., F.G.S.

Specimen of Lazulite from Madagascar, exhibited on behalf of the Rev. Richard Baron by W. W. Watts, Esq., M.A., F.G.S.

May 23rd, 1894.

Dr. Henry Woodward, F.R.S., President, in the Chair.

Adolphus Eugene Walton, Esq., Henley Cottage, Hendon, N.W.; and Arthur Prangley Wilson, Esq., Assoc.M.Inst.C.E., Rodwold, Chislehurst, were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communications were read:—

1. 'On the Stratigraphy and the Physiography of the Libyan Desert of Egypt.' By Captain H. G. Lyons, R.E., F.G.S.

2. 'Notes on the Geology of South-eastern Africa.' By David Draper, Esq., F.G.S.

3. 'The Occurrence of Dolomite in South Africa.' By David Draper, Esq., F.G.S.

4. 'Contributions to the Geology of British East Africa.—Part I. The Glacial Geology of Mount Kenya.' By J. W. Gregory, D.Sc., F.G.S.

The following specimens were exhibited:—

Specimens of Rocks, Fossil Wood, Flint-implements, etc., and also Microscope-sections, exhibited by Capt. H. G. Lyons, R.E., F.G.S., in illustration of his paper.

Specimens of Conglomerate, from the Table Mountain Series, Zululand, and a specimen of Anthracite from the Molteno Beds, St. Lucia Bay, exhibited by D. Draper, Esq., F.G.S., in illustration of his papers.

Rock-specimens and Gold Nuggets from Pilgrim's Rest, etc., Lydenburg District, Transvaal, exhibited by Nicol Brown, Esq., F.G.S.

Microscope-section of a specimen from the Cave Sandstone of the Harrismith District, Orange Free State, exhibited by the President.

A Quartzite-boulder found in the Chalk of West Thurrock, exhibited by J. J. H. Teall, Esq., M.A., F.R.S., Sec.G.S., on behalf of W. Martin Leake, Esq.

June 6th, 1894.

Dr. Henry Woodward, F.R.S., President, in the Chair.

Finlay Lorimer Kitchin, Esq., B.A., St. John's College, Cambridge, was elected a Fellow; and Monsieur P. de Loriol-Lefort, of Geneva, a Foreign Correspondent of the Society.

The names of certain Fellows were read out for the first time, in conformity with the Bye-laws, Section VI. Article 5, in consequence of the non-payment of arrears of contributions.

The List of Donations to the Library was read.

The following communications were read:—

1. 'On the Banded Structure of some Tertiary Gabbros in the Isle of Skye.' By Sir Archibald Geikie, LL.D., D.Sc., F.R.S., F.G.S., and J. J. H. Teall, Esq., M.A., F.R.S., Sec.G.S.

2. 'On the Microscopical Structure of the Derbyshire Carboniferous Dolerites and Tuffs.' By H. H. Arnold-Bemrose, Esq., M.A., F.G.S.

3. 'A Comparison of the Permian Breccias of the Midlands with the Upper Carboniferous Glacial Deposits of India and Australia.' By R. D. Oldham, Esq., F.G.S.

The following specimens were exhibited:—

Rock-specimens, microscope-sections, and lantern-photographs, exhibited by Sir Archibald Geikie, LL.D., D.Sc., F.R.S., F.G.S., and J. J. H. Teall, Esq., M.A., F.R.S., Sec.G.S., in illustration of their paper.

Specimens, microscope-sections, and lantern-photographs of sections of Derbyshire Carboniferous Dolerites and Tuffs, exhibited by H. H. Arnold-Bemrose, Esq., M.A., F.G.S., in illustration of his paper.

Specimens exhibited by the Geological Survey of England and Wales, to illustrate the paper by R. D. Oldham, Esq., F.G.S.

Scratched fragments of Permian Breccia from Abberley, and a Facetted Pebble from the Carboniferous Boulder-bed of the Salt Range, India, exhibited by R. D. Oldham, Esq., F.G.S., in illustration of his paper.

Kantengerölle from Copitz near Dresden, exhibited by R. D. Oldham, Esq., F.G.S.

June 20th, 1894.

Dr. Henry Woodward, F.R.S., President, in the Chair.

James Knight, Esq., M.A., B.Sc., 121 Kenmure Street, Pollokshields, Glasgow, was elected a Fellow; and Professor Alphonse Renard, of Ghent, a Foreign Member of the Society.

The following names of Fellows of the Society were read out for the second time, in conformity with the Bye-laws, Section VI. Article 5, in consequence of the non-payment of arrears of con-

tributions:—W. J. R. COWELL, Esq.; T. A. DASH, Esq.; F. J. A. MATTHEWS, Esq.; C. PARKER, Esq.; E. M. RICHARDS, Esq.; Rev. J. C. ROBERTS; S. ROGERS, Esq.; J. RUSCOE, Esq.; U. P. SWINBURNE, Esq.; Dr. J. E. TAYLOR; T. C. TOWNSEND, Esq.; C. H. TRINKS, Esq.; and S. J. TRUSCOTT, Esq.

The List of Donations to the Library was read.

The following communications were read:—

1. 'On Deep Borings at Culford and Winkfield, with Notes on those at Ware and Cheshunt.' By W. Whitaker, Esq., B.A., F.R.S., F.G.S., and A. J. Jukes-Browne, Esq., B.A., F.G.S.

2. 'The Bargate Beds of Surrey, and their Microscopic Contents.' By Frederick Chapman, Esq., F.R.M.S. (Communicated by Prof. T. Rupert Jones, F.R.S., F.G.S.)

3. 'On Deposits from Snowdrift, with Especial Reference to the Origin of the Loess and the Preservation of Mammoth-remains.' By Charles Davison, Esq., M.A., F.G.S.

4. 'Additions to the Fauna of the *Olenellus*-zone of the North-west Highlands.' By B. N. Peach, Esq., F.R.S., F.G.S. (Communicated by permission of the Director-General of the Geological Survey.)

5. 'Questions relating to the Formation of Coal-Seams, including a New Theory of them: suggested by Field and other Observations made during the past decade on both sides of the Atlantic.' By W. S. Gresley, Esq., F.G.S.

6. 'Observations regarding the Occurrence of Anthracite generally, with a new Theory as to its Origin.' By W. S. Gresley, Esq., F.G.S.

7. 'The Igneous Rocks of the Neighbourhood of Builth.' By Henry Woods, Esq., M.A., F.G.S.

8. 'On the Relations of some of the Older Fragmental Rocks in North-west Caernarvonshire.' By Prof. T. G. Bonney, D.Sc., LL.D., F.R.S., F.G.S., and Miss Catherine A. Raisin, B.Sc.

The following specimens were exhibited:—

Specimens from the Deep Borings at Culford, Ware, and Turnford, exhibited by W. Whitaker, Esq., B.A., F.R.S., F.G.S., and A. J. Jukes-Browne, Esq., B.A., F.G.S., in illustration of their paper.

Rock-specimens and microscope-sections from the Bargate Beds of Surrey, exhibited by F. Chapman, Esq., in illustration of his paper.

Specimen of Deposit from the surface of a Snowdrift, exhibited by Charles Davison, Esq., M.A., F.G.S., in illustration of his paper.

Specimens exhibited by the Geological Survey in illustration of the paper on the *Olenellus*-zone Fauna by B. N. Peach, Esq., F.R.S., F.G.S.

Microscope-sections and rock-specimens from the neighbourhood of Builth, exhibited by Henry Woods, Esq., M.A., F.G.S., in illustration of his paper.

Rock-specimens and microscope-sections, exhibited in illustration of their paper by Prof. T. G. Bonney, D.Sc., LL.D., F.R.S., F.G.S., and Miss Catherine A. Raisin, B.Sc.

A Special General Meeting was held at 7.45 p.m., before the Ordinary General Meeting, for the purpose of altering and re-enacting Article 6, Section VI. of the Bye-laws, which, as now altered, reads as follows :—

A Fellow may at any time compound for future Annual Contributions, that of the current year inclusive, by payment of Thirty-five pounds, or if elected before the 1st November, 1894, by a payment of Thirty-one pounds Ten shillings, or if elected before the 1st November, 1877, by a payment of Twenty-one pounds. If he has already paid the Contribution for the current year, or any part of it, such payment shall be reckoned as forming a portion of the Composition.

N.B.—As to the Composition-fee for Non-Resident Fellows elected between November 2nd, 1859, and March 1st, 1862, see Appendix A to Bye-Laws.

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Amsterdam. Jaarboek van het Mijnwezen in Nederlandsch Oost-Indië. Jaargang 22e. 1893. Technisch en Administratief en Wetenschappelijk Gedeelte. 1893. And Atlas. *Presented by His Excellency the Netherlands Minister for the Colonies.*

A. Hooze. Topografische, Geologische, Mineralogische en Mijnbouwkundige Beschrijving van een gedeelte der afdeeling Martapoera in de residentie Zuider- en Oosterafdeeling van Borneo, 1.

Baltimore. U. S. Department of Agriculture. Weather Bureau. *See* Books. United States.

Barnsley (Newcastle-upon-Tyne). Midland Institute of Mining, Civil, and Mechanical Engineers. Proceedings. Vol. xiii. Parts 120–122. 1893.

Basel. Schweizerische naturforschende Gesellschaft. Verhandlungen, 1892. 1892.

Bericht der geologischen Kommission für das Jahr 1891–92, 99.

——. Schweizerische paläontologische Gesellschaft. Abhandlungen. Vol. xx. 1893. 1894. *Purchased.*

E. Greppin. Étude sur les mollusques des couches coralligènes d'Oberbuchsitten.—H. Haas. Kritische Beiträge zur Kenntniss der jurassischen Brachiopodenfauna des Juragebirges, III. Theil.—R. Haeusler. Die Lagenidenfauna der Pholadomyenmergel von St. Sulpice.—P. de Loriol. Description des mollusques des couches séquaniennes de Tonnerre, avec une étude stratigraphique par J. Lambert.

Bath. Bath Natural History and Antiquarian Field Club. Proceedings. Vol. viii. No. 1, 1894. 1894.

Report of Excursion to Brockley Combe and Congresbury, 58.

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